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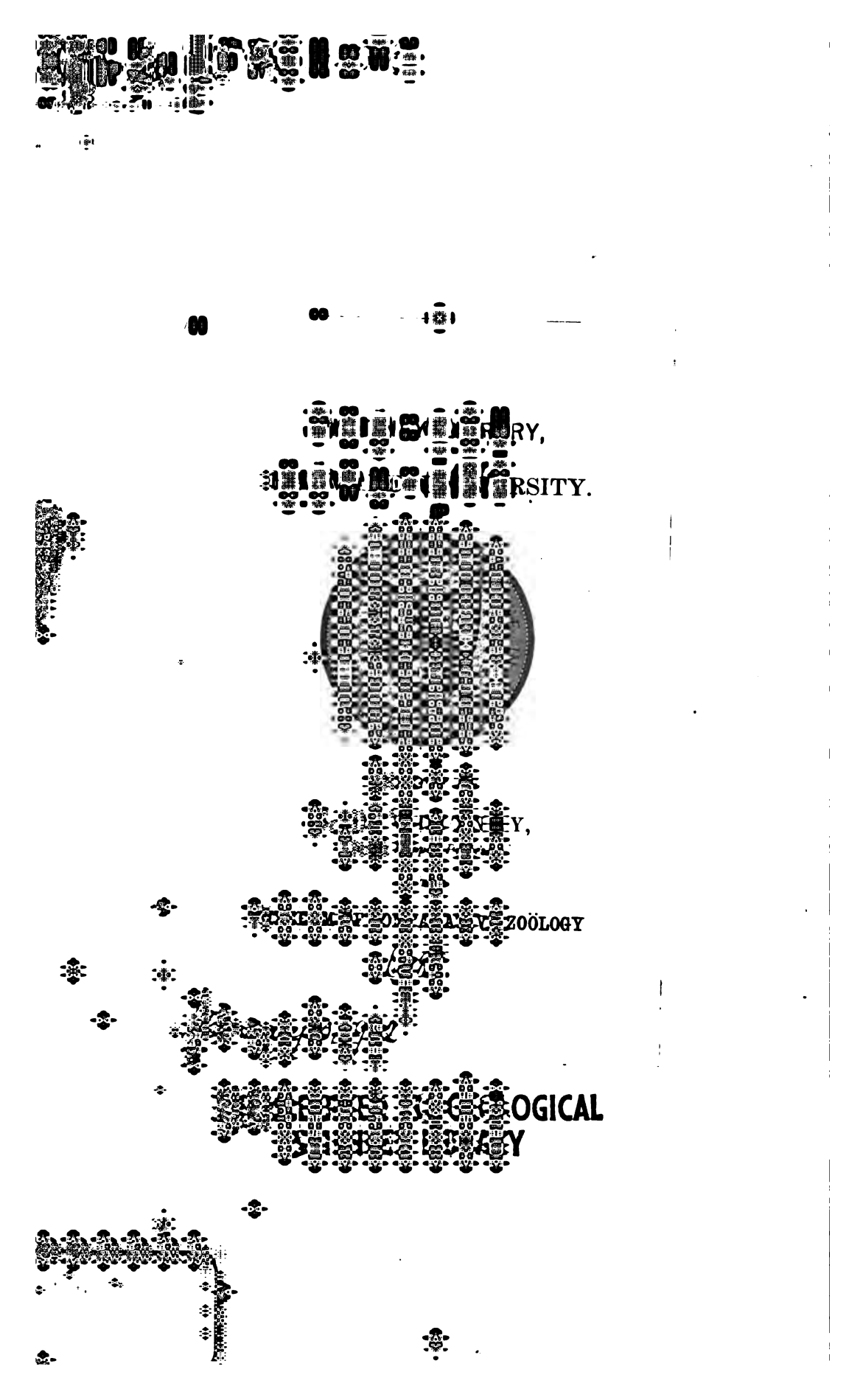

TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF MINING ENGINEERS.

VOL. XXIII.

BEING PART II. OF THE PROCEEDINGS, PAPERS AND DISCUSSIONS OF THE CHICAGO MEETING OF 1893, CONSTITUTING DIVISIONS C AND D OF THE INTERNATIONAL ENGINEERING CONGRESS.

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AT THE OFFICE OF THE SECRETARY.
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PREFACE.

The present volume, and Volume XXII., issued immediately before it, contain the papers and discussions of the Chicago Meeting of the Institute, held in August, 1893, and constituting Divisions C and D, devoted respectively to Mining and Metallurgy, of the International Engineering Congress, held in connection with the World's Columbian Exposition. No attempt has been made to separate in publication the papers of the two Divisions, or to arrange them in the order of their presentation at the meeting. They appear in these volumes in the order in which they have been made ready for final publication.

Volume XXIV. will contain additional discussions of these papers, held at subsequent meetings of the Institute.

R. W. R.

May 15, 1894.

CONTENTS.

	PAGE
OFFICERS, HONORARY MEMBERS AND "FOREIGN" MEMBERS,	vii
MEMBERS AND ASSOCIATES,	x
PAST AND PRESENT OFFICERS,	lxxiv
LIST OF MEETINGS,	lxxvi
PUBLICATIONS,	lxxviii
RULES,	lxxxi

PROCEEDINGS.

Condensed proceedings of the Chicago meeting, being part of the International Engineering Congress, August, 1893. (For full proceedings, see vol. xxii.) lxxxv

PAPERS.

A New Process for the Production of Pig-Iron, Refined Iron, Ingot-Metal and Weld-Metal, by ALEXANDER SATTMAN and ANTON HOMATSCH,	3
The Micro-structure of Ingot-Iron in Cast Ingots, by A. MARTENS (See Discussion, "Physics of Steel," p. 608),	37
Experimental Investigations on the "Loss of Head" of Air-Currents in Underground Workings, by D. MURGUE,	63
Further Observations on the Relations Between the Chemical Constitution and Physical Character of Steel, by WILLIAM R. WEBSTER (See Discussion, "Physics of Steel," p. 608),	113
The Consumption of Fuel in the Taylor Gas-Producer Plants at the Aspen and Marsac Mills Compared, by C. A. STETEFELDT (See Discussion, p. 585),	134
The Limitations of the Gold Stamp-Mill, by T. A. RICKARD (See Discussion, p. 545),	137
Iron Alloys with Special Reference to Manganese Steel, by R. H. HADFIELD,	148
The Genesis of Ore-Deposits, by F. POŠEPNÝ (See Discussion, p. 587),	197
Review of American Blast-Furnace Practice, by E. C. POTTER (See Discussion, p. 577),	370
Sulphur in Cast-Iron, by W. J. KEEP,	382
Electricity in Mining, by F. O. BLACKWELL,	399
Recent Advances in Pyrometry, by W. C. ROBERTS-AUSTIN,	407
The Growth of American Mining-Schools and their Relation to the Mining Industry, by SAMUEL B. CHRISTY (See Discussion, p. 657),	444
The Heat-Treatment of Steel, by HENRY M. HOWE (See Discussion, "Physics of Steel," p. 608),	466

DISCUSSIONS.

Discussion of paper of Mr. Rickard (See p. 137),	545
Discussion of paper of Mr. Potter (See p. 370),	577
Discussion of paper of Mr. Stetefeldt (See p. 134),	585
Discussion of paper of Prof. Posepny (See p. 197),	587
Discussion: The Physics of Steel,	608
Discussion of paper of Prof. Christy (See p. 444),	657

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Corrected to May, 1894.

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*Bowron, William M., ... South Pittsburg, Tenn. '81
*Boyd, C. R., ... Wytheville, Va. '76
*Boyd, Henry A., . . . Buffalo Steam Pump Co., Buffalo, N. Y. '86
*Boyd, John D., ... Uniontown, Pa. '80
*Boyd, John Y., ... Tyrone Iron Co., Harrisburg, Pa. '86
*Boyer, Jerome L., ... Reading, Pa. '84
†Boyer, William McHose, . . 157 N. Fifth Street, Reading, Pa. '91
*Bradburn, J. A., ... Solvay Process Co., Syracuse, N. Y. '89
**Bradley, Frederick W., ... Kellogg, Idaho. '91
*Bradley, G. L., ... 2035 P Street, N. W., Washington, D. C. '74
*Bradley, William H., ... Mingo Junction, Ohio. '89
*Brady, Andrew, ... Cornwall, Pa. '87
*Brady, Samuel, . . . Foot of Woodward Avenue, Detroit, Mich. '89
*Brakes, James, . . . Crown Point Iron Co., Crown Point, N. Y. '94
*Bramwell, J. H., . . 10 W. Twenty-ninth Street, New York City. '71
*Branner, Prof. John C., Leland Stanford Junior University, Palo Alto, Cal. '84
*Braschi, Victor M., . . . Apartado 830, City of Mexico, Mexico. '91
*Bratnober, H., ... 400 A. Oak Street, San Francisco, Cal. '87
*Brauns, H., ... Dortmund, Germany. '91
*Bray, William A., . . . P. O. Box 56, Barry, El Paso Co., Colo. '80
*Breckenridge, Cabell, . . . 1028 Russell Street, Covington, Ky. '84
*Breen, James, ... Butte, Mont. '87
*Bretherton, S. E., ... P. O. Box 468, Leadville, Colo. '89
*Bretherton, W. L., ... P. O. Box 1340, Tacoma, Wash. '87
*Brewer, William M., ... Heflin, Cleburne Co., Ala. '93
*Brewster, E. E., . . . 508 C Street, East, Iron Mountain, Mich. '88
*Bridgman, H. L., ... Blue Island, Ill. '79
*Briggs, Frank O., ... Trenton, N. J. '93
*Brinsmade, Henry N., . . 69 West Fiftieth Street, New York City. '81
*Britton, J. Blodget, ... Warrenton, Va. '72
*Brock, Arthur, ... Lebanon, Pa. '87
*Brock, Charles, . . Boonton Iron and Steel Co., Boonton, N. J. '81
*Brockway, William L., . . . 260 W. 21st Street, New York City. '90
*Broden, Albert, ... Reading, Pa. '89
**Brodie, W. M., ... Batopilas, Chihuahua, Mexico. '72
*Brooke, George, ... Birdsboro, Berks Co., Pa. '81
*Brooke, Henry, ... Jeansville, Luzerne Co., Pa. '93
*Brooke, Horace L., ... Baltimore, Md. '92
*Brooks, R. G., ... P. O. Box 124, Scranton, Pa. '84
†Brooks, T. B., ... Newburgh, N. Y. '72
*Brown, Alexander E., . . 1151 Prospect Street, Cleveland, Ohio. '75
**Brown, Amos P., ... Stenton Avenue, Germantown, Pa. '88

**Brown, A. T.,	372 Flinders Lane, Melbourne, Australia.	'91
*Brown, Austin H.,	Anaconda, Mont.	'92
*Brown, D. P.,	Lost Creek P. O., Schuylkill Co., Pa.	'72
*Brown, E. C.,	Patton, Cambria Co., Pa.	'86
*Brown, Edward L.,	Care Inman S. S. Line, 32 S. Clark St., Chicago, Ill.	'81
*Brown, Elwin F.,	Iron Mountain, Mich.	'91
†Brown, Fayette,	863 Euclid Avenue, Cleveland, Ohio.	'75
*Brown, Harvey H.,	103 Superior Street, Cleveland, Ohio.	'76
*Brown, John H.,	621 Temple Court, New York City.	'92
†Brown, Lewis V.,	Star Furnace Co., Jackson, Ohio.	'90
*Brown, Robert G.,	P. O. Box 946, Butte, Mont.	'89
*Brown, Samuel L.,	Lock Box 166, South Chicago, Ill.	'89
*Brown, T. Forster,	Guildhall Chambers, Cardiff, So. Wales.	'86
*Brown, William,	Phœnix Iron Works, Phœnixville, Pa.	'91
*Browne, Arthur Benjamin,	119 Water Street, Boston, Mass.	'93
**Browne, Arthur R.,	West Coast, Tasmania.	'90
*Browne, Ross E.,	Nevada Block, San Francisco, Cal.	'94
**Brunton, D. W.,	Aspen, Colo.	'83
*Brush, Prof. George J.,	New Haven, Conn.	'75
*Bryant, Louis E.,	Harriman, Roane Co., Tenn.	'91
*Buchanan, C. G.,	143 Liberty Street, Room 225, New York City.	'90
*Bucherer, Alfred H.,	Ithaca, N. Y.	'91
*Buck, F. P.,	Dominion Line Co., Sherbrooke, Quebec, Canada.	'93
*Buck, Stuart M.,	Maybeury, McDowell Co., W. Va.	'71
*Buhl, Frank,	Sharon, Pa.	'91
*Bulkley, F. G.,	Aspen M. & S. Co., Aspen, Colo.	'82
*Bulkley, Frank,	Aspen, Colo.	'89
*Bulkley, Henry W.,	Times Building, Room 125, New York City.	'79
*Bulley, Reginald H.,	Canton, Ohio.	'78
*Bullock, M. C.,	1187 Washington Boulevard, Chicago, Ill.	'74
*Bunning, Charles Z.,	Care The Borax Co., Ltd., 2 Macri Khan, Constantinople, Turkey.	'85
*Burbidge, Frederick,	Wardner, Idaho.	'87
*Burchell, H. C.,	St. John's, Newfoundland.	'83
†Burden, Henry, 2d,	Cazenovia, N. Y.	'92
**Burden, H. H.,	49 Wall Street, New York City.	'83
*Burden, James A.,	Woodside, Troy, N. Y.	'76
†Burke, M. D.,	41 Pikes Building, Cincinnati, Ohio.	'74
*Burlingame, E. E.,	1736 Lawrence Street, Denver, Colo.	'82
*Burlingham, C. L.,	Denver Athletic Club, Denver, Colo.	'86
*Burnham, William,	220 S. Fourth Street, Philadelphia, Pa.	'76
*Burns, Prof. J. A.,	P. O. Box 206, Atlanta, Ga.	'86
*Burrell, Alexander,	Marysville, Mont.	'92
*Burritt, Wilmot W.,	16 Smith Street, Brooklyn, N. Y.	'88
**Burt, Charles S.,	1114 Monadnock Building, Chicago, Ill.	'82
*Burt, Horace E.,	524 Boston Block, Minneapolis, Minn.	'90
†Burwell, N. L.,	21 Quincy Street. Chicago, Ill.	'94
*Bush, E. Renshaw,	104 John Street, New York City.	'85
*Butters, Charles,	P. O. Box 1891, Johannesburg, Transvaal, So. Africa.	'83
*Button, Edward,	East Rand Proprietary Co., Johannesburg, Transvaal, So. Africa.	'93

*Büttner, Arthur,	Smelting Works, San Andres de la Sierra, Durango, Mexico.	'93
*Byers, A. M.,	98 Water Street, Pittsburgh, Pa.	'86
*Cabot, John W.,	Fisher Avenue, Brookline, Mass.	'80
*Cadle, Cornelius, Jr.,	Blocton, Bibb Co., Ala.	'83
*Cady, Charles H.,	Mineville, N. Y.	'88
*Calhoun, W. H., Jr.,	251 DeKalb Avenue, Brooklyn, N. Y.	'88
*Calhoun, W. S.,	Phœnix Building, Chicago, Ill.	'92
*Call, Arthur B.,	Amador City, Cal.	'93
*Camp, James M.,	Duquesne Steel Works, Duquesne, Pa.	'83
*Campbell, D. M.,	Leechburg, Armstrong Co., Pa.	'89
*Campbell, E. D.,	108 Hill Street, Ann Arbor, Mich.	'93
*Campbell, Edward S., Jr.,	Brookside, Jefferson Co., Ala.	'86
*Campbell, H. H.,	Steelton, Dauphin Co., Pa.	'81
*Campbell, John H.,	Yarnell, Yavapai Co., Ariz.	'88
*Campbell, Marius R.,	U. S. Geol. Survey, Washington, D. C.	'92
*Canby, R. C.,	Argentine, Kan.	'82
†Canfield, A. Cass,	40 Park Avenue, New York City.	'76
*Canfield, Fred. A.,	Dover, N. J.	'74
*Capacci. Celso,	Valfonda 7, Florence, Italy.	'94
*Carkeek, John,	P. O. Box 350, Butte, Mont.	'93
*Carll, John F.,	Pleasantville, Pa.	'86
*Carlton, James G.,	Care J. M. Restrepo, Honda, Colombia, S. A.	'92
*Carnahan, Charles T.,	P. O. Box 566, Leadville, Colo.	'89
*Carnegie, Andrew,	5 W. Fifty-first Street, New York City.	'88
*Carney, Henry C.,	P. O. Box 770, Butte, Mont.	'89
*Carney, James A.,	C. B. and Q. R.R. Co., Aurora, Ill.	'92
*Carpenter, Prof. F. R.,	Deadwood, So. Dakota.	'87
*Carpenter, J. H.,	Reading, Pa.	'91
*Carr, P. E. O.,	Mina Cabezas Pasto, Pueblo de Guzman, Huelva, Spain.	'92
†Carrel, F. J.,	Spokane, Wash.	'87
*Carroll, Lafayette D.,	47 Carondelet Street, New Orleans, La.	'88
*Carson, A. C.,	Butte, Mont.	'84
*Carson, James P.,	206 Broadway, New York City.	'82
*Carter, Frank,	Pottsville, Pa.	'73
*Carter, Samuel P., Jr.,	1316 Connecticut Avenue, Washington, D. C.	'87
*Carter, Thomas H.,	Merchants' National Bank Building, Helena, Mont.	'92
†Cary, John S.,	1539 University Building, Chicago, Ill.	'93
*Case, W. H.,	Charlotte, N. C.	'78
*Casterline, R. D.,	663 Brooklyn Street, W. Philadelphia, Pa.	'92
Castillo, Sr. Don Antonio Del,	City of Mexico, Mexico.	
*Cazin, Frank,	Room 421, Cheesman Building, Denver, Colo.	'89
*Cazin, F. M. F.,	1027 Washington Street, Hoboken, N. J.	'90
*Chadwick, Walter M.,	P. O. Box 230, Bayonne, N. J.	'83
*Chalfant, John W.,	Pittsburgh, Pa.	'73
*Chalmers, George,	Morro Velho, Brazil.	'92
*Chamberlain, H. S.,	Chattanooga, Tenn.	'75
*Chambers, R. C.,	P. O. Box 601, Salt Lake City, Utah.	'86
*Chambers, Robert E.,	Eureka, Pictou Co., Nova Scotia.	'91
*Chance, Dr. H. Martyn,	Room 418, Drexel Building, Philadelphia, Pa.	'74

*Chandler, C. F., . School of Mines, Columbia College, New York City. '90
*Channing, J. Parke, . . . P. O. Box 27, Iron Mountain, Mich. '84
*Chanute, Arthur, ... Globe S. and R. Co., Denver, Colo. '82
*Chanute, O., ... 413 E. Huron Street, Chicago, Ill. '79
*Chaper, Maurice, ... 31 rue St. Guillaume, Paris, France. '79
*Chapman, Charles W., . . 39 Queen Street, Melbourne, Australia. '91
*Charleton, A. G., Care G. P. Charleton, Dover Court, Essex, England. '81
*Chase, Frank D., . . Care Grasselli Chemical Co., Cleveland, Ohio. '84
*Chase, Harvey S., ... 136 Liberty Street, New York City. '92
*Chatard, Thomas M., . . 1410 G Street, N.W., Washington, D. C. '88
*Chauvenet, S. H., . . . 220 S. Fourth Street, Philadelphia, Pa. '81
*Chauvenet, W. Marc, . . . 709 Pine Street, St. Louis, Mo. '90
*Chazal, Philip E., ... 68 Meeting Street, Charleston, S. C. '81
*Cheever, J. D., ... 15 Park Row, New York City. '89
*Chenhall, James W., . . Dart Villa, Totnes, Devonshire, England. '85
*Cherry, William S., ... Streator, Ill. '75
*Chester, Prof. A. H., . . Rutgers College, New Brunswick, N. J. '71
*Chester, Edward, D., . 23 Bucklersbury, London, E. C., England. '90
*Cheyney, Samuel W., ... Johnsville, Plumas Co., Cal. '87
*Chism, Richard E., . 3 Independencia No. 1, City of Mexico, Mexico. '80
*Chouteau, Pierre, ... St. Louis, Mo. '76
*Christie, Fred. W., . . . Bedford Station, Halifax, Nova Scotia. '85
*Christy, Prof. S. B., ... State University, Berkeley, Cal. '83
*Church, Albert K., ... Hazelwood, Pittsburgh, Pa. '92
*Church, E. D., Jr., ... 127 Milton Street, Brooklyn, N. Y. '88
*Church, Prof. John A., . . . 40 Wall Street, New York City. '72
*Church, John B., ... Geneva, N. Y. '81
*Church, Townsend V., ... Ill. Steel Co., So. Chicago, Ill. '82
*Church, Walter S., ... Care J. B. Church, Geneva, N. Y. '81
†Chynoweth, B. F., ... Rockland, Mich. '76
*Claghorn, Clarence R., ... Buffington, Indiana Co., Pa. '84
*Claghorn, J. Raymond, . . 204 Walnut Place, Philadelphia, Pa. '91
*Clapp, George H., ... 116 Water Street, Pittsburgh, Pa. '83
*Clark, Charles J., ... French Gulch, Shasta Co., Cal. '90
*Clark, Clarence M., . . . Bullitt Building, Philadelphia, Pa. '88
*Clark, Ellis, Jr., ... Phœnix, Ariz. '74
*Clark, Edmund, ... Braddock, Pa. '94
*Clark, Edwin M., ... Butte, Mont. '91
*Clark, F. W., ... 231 Warren Street, Chicago, Ill. '82
*Clark, Joseph K., ... Butte, Mont. '87
**Clark, Maurice, . 8 New Montgomery Street, San Francisco, Cal. '86
*Clark, William A., ... Butte, Mont. '82
*Clark, William P., ... Yuscaran, Honduras, C. A. '92
*Clarke, E. A. S., . . Care Illinois Steel Co., South Chicago, Ill. '85
*Clarke, Thomas C., ... 44 Broadway, New York City. '76
*Claudet, Arthur C., . 6 and 7 Colman Street, London, England. '86
*Claussen, F. F., ... U. S. Mint, New Orleans, La. '76
*Claypool, W. M., . . El Paso Smelting Works, El Paso, Texas. '84
*Cleland, E. Davenport, . . . Broken Hill, New South Wales. '90
*Clement, F. H., ... Niagara Falls, N. Y. '92
**Clement, V. M., Care Barnato Bros., Johannesburg, Transvaal, So. Africa. '87

**Clemes, J. H.,	Cheriton, Chelston on Torquay, England.	'81
*Clerc, F. L.,	1632 Monadnock Building, Chicago, Ill.	'87
**Cliff, John,	"The Mentone," Dearborn Ave. and Erie St., Chicago, Ill.	'80
*Clymer, Edward T.,	Allentown, Pa.	'82
*Clymer, Lee S.,	Riegelsville, Pa.	'86
*Cockburn, James D.,	729 Highland Avenue, Thurlow, Pa.	'93
*Codington, E. W.,	Bartow, Polk Co., Fla.	'90
*Coe, W. W.,	Roanoke, Va.	'83
*Cofrode, J. H.,	257 S. Fourth Street, Philadelphia, Pa.	'92
*Coffin, Charles E.,	Muirkirk, Md.	'82
*Coffin, Harry W.,	Tuscarora, Nevada.	'90
*Coffin, W. C.,	55 Water Street, Pittsburgh, Pa.	'92
*Coggin, F. G.,	Lake Linden, Mich.	'80
*Coghlan, F. M.,	Catorce, San Luis Potosi, Mexico.	'91
**Cogswell, W. B.,	Room 25, White Building, Syracuse, N. Y.	'72
*Cohen, H. A.,	Helene (via Pioche), Nevada.	'89
*Colbath, L. U.,	Salt Lake City, Utah.	'87
*Colby, Albert L.,	P. O. Box 458, Bethlehem, Pa.	'83
†Colby, Joseph L,	36 Wall Street, New York City.	'88
*Cole, Eugene M.,	118 W. Forty-ninth Street, New York City.	'86
*Cole, T. F.,	Negaunee, Mich.	'90
*Coleman, Charles P.,	Care L. V. R. R. Co., South Bethlehem, Pa.	'88
*Coleman, R. J.,	Adams Mining Co., Leadville, Colo.	'89
**Collin, Emile,	62 rue de Miromesnil, Paris, France.	'86
*Collingwood, Francis,	Elizabeth, N. J.	'82
†Collins, H. E.,	Bank of Commerce Building, Pittsburgh, Pa.	'76
*Collins, W. J.,	P. O. Box 308, Melbourne, Victoria, Australia.	'93
*Colton, Charles A.,	21 West Park Street, Newark, N. J.	'74
**Colvin, Verplanck,	N. Y. State Land Survey, Albany, N. Y.	'81
*Colwell, James M.,	Kittanning Iron Co., Kittanning, Pa.	'93
*Colyar, Louis S.,	Chattanooga, Tenn.	'85
*Comstock, Prof. Theodore B.,	University of Arizona, Tucson, Ariz.	'80
*Comstock, William O.,	38 W. Seventy-fifth Street, New York City.	'90
*Conant, Henry D.,	203 W. Seventy-eighth Street, New York City.	'88
*Conkling, John P.,	Glens Falls, Warren Co., N. Y.	'92
*Conlin, T. N.,	Illinois Steel Co., Joliet, Ill.	'91
*Connell, William,	Scranton, Pa.	'87
*Connell, W. A.,	Craig City, Va.	'86
*Conner, Eli T.,	Winton, Lackawanna Co, Pa.	'92
*Connor, Benjamin Franklin,	Columbia, Pa.	'91
*Connor, Charles,	Uniontown, Fayette Co., Pa.	'86
*Connor, S. B.,	2009 Central Avenue, Alameda, Cal.	'88
*Conradson, Pontus H.,	Great Northern Ry. Co., St. Paul, Minn.	'92
*Conro, Albert,	Milwaukee, Wis.	'88
*Convers, George G.,	South Bethlehem, Pa.	'86
*Converse, John H.,	500 North Broad Street, Philadelphia, Pa.	'83
*Conyngham, Charles M.,	Wilkes-Barre, Pa.	'91
*Conyngham, John N.,	Wilkes-Barre, Pa.	'91
*Cook, Edgar S.,	Warwick Iron Co., Pottstown, Pa.	'77
*Cook, F. S.,	216 Stewart Building, New York City.	'91
*Cook, Robert A.,	New Brunswick, N. J.	'83

*Coolidge, Walter G.,	1st Nat. Bank Building, Chicago, Ill.	'82
*Cooper, Edward,	17 Burling Slip, New York City.	'74
*Cooper, H. P.,	Pottsville, Pa.	'81
*Copeland, F. K.,	15 N. Clinton Street, Chicago, Ill.	'87
*Corbould, William Henry,	Coolgardie, Western Australia.	'92
*Corey, W. E.,	Carnegie Steel Co., Homestead, Pa.	'94
*Corning, C. R.,	223 Crocker Building, San Francisco, Cal.	'86
*Corning, Frederick G.,	Mills Building, Room 25, New York City.	'77
*Corse, Montgomery B.,	Virginia Military Institute, Lexington, Va.	'91
*Corthell, E. L.,	11 Broadway, New York City.	'91
*Coryell, Torbert,	Lambertville, N. J.	'83
*Coste, Eugene,	132 Lexington Avenue, Buffalo, N. Y.	'87
*Countryman, T. R.,	P. O. Box 651, Cripple Creek, Colo.	'89
*Courtis, W. M.,	449 Fourth Avenue, Detroit, Mich.	'71
*Coutie, William,	29 Fourth Street, Troy, N. Y.	'84
*Cowland, Charles D.,	McPhee Building, Denver, Colo.	'91
*Cowles, Alfred H.,	656 Prospect Street, Cleveland, Ohio.	'86
*Cox, E. T.,	10 Wall Street, New York City.	'90
*Cox, Justice, Jr.,	218 S. Fourth Street, Philadelphia, Pa.	'89
*Cox, William J.,	P. O. Box 733, Aspen, Colo.	'93
†Coxe, Alexander B.,	Eckley, Luzerne Co., Pa.	'80
†Coxe, Alexander B., Jr.,	Drifton, Luzerne Co., Pa.	'88
**Coxe, Eckley B.,	Drifton, Luzerne Co., Pa.	'71
†Coxe, Eckley B., Jr.,	Drifton, Luzerne Co., Pa.	'93
*Coxe, MacGrane,	51 Wall Street, New York City.	'92
*Coxe, W. E. C.,	Columbus & Hocking Coal & Iron Co., Columbus, Ohio.	'74
*Crabtree, Fred.,	441 Ringold Avenue, McKeesport, Pa.	'90
*Crafts, Walter,	Columbus, Ohio.	'71
*Cramer, Stuart W.,	U. S. Assay Office, Charlotte, N. C.	'89
*Crandell, W. R.,	Dahlonega, Ga.	'86
†Crane, Theron I.,	Bullitt Building, Philadelphia, Pa.	'92
*Crawford, Hugh A.,	411 Olive Street, St. Louis, Mo.	'75
*Crawford, John J.,	24 Fourth Street, San Francisco, Cal.	'73
*Crawford, John L.,	Newcastle, Pa.	'84
*Cremer, J. H.,	24 Superior Street, Cleveland, Ohio.	'75
*Crichton, Donald G.,	Nundle via Tamworth, N. S. Wales.	'89
**Crocker, A. L.,	2515 Blaisdel Avenue, Minneapolis, Minn.	'80
*Crocker, George A.,	32 Cliff Street, New York City.	'79
*Crocker Kendall F.,	P. O. Box 1551, Fitchburg, Mass.	'94
*Crooke, Robert L.,	22 Burling Slip, New York City.	'89
*Crooker, Ralph, Jr.,	Acton, Mass.	'81
*Crookston, A. W.,	19 Wellington Street, Glasgow, Scotland.	'80
†Cross, Arthur D.,	1719 Broderick Street, San Francisco, Cal.	'91
*Crowell, Benedict,	937 Prospect Street, Cleveland, Ohio.	'93
*Crowther, Benjamin,	Etna, Allegheny Co., Pa.	'76
*Croxton, Samuel W.,	Canal Dover, Ohio.	'75
*Croze, W. W. J.,	Houghton, Mich.	'92
*Crozer, S. A., Jr.,	2005 Delancey Place, Philadelphia, Pa.	'83
*Cullingworth, George R.,	101 Walker Street, New York City.	'87
*Cullum, James B.,	Lebanon, Pa.	'91
*Cummer, F. D.,	613 The Arcade, Cleveland Ohio.	'83

*Cummings, George P., ... Marquette, Mich. '81
*Cummings, William N, Chicago & Aurora Smelting & Ref. Co., Aurora, Ill. '93
*Cunningham, James S., ... Punxsutawney, Pa. '83
*Cunningham, J. L., ... 145 Fair Street, Paterson, N. J. '82
†Curry, George H., ... Prescott, Ariz. '92
*Curry, Henry M., . . Carnegie, Phipps & Co., Ltd., Pittsburgh, Pa. '79
*Curtis, Gram, ... 612 Lewis Block, Pittsburgh, Pa. '80

*Daggett, Ellsworth, ... Salt Lake City, Utah. '73
*Dagron, James G., ... B. & O. R. R., Baltimore, Md. '84
*Daelen, R. M., ... Düsseldorf, Germany. '91
*Dale, Thomas H., ... Scranton, Pa. '87
*Daleas, Paul, ... 58 rue de Rome, Paris, France. '88
*Dalgleisch, Reginald H., . . . Elizabethton, Carter Co., Tenn. '92
*Dalton, George, . . . The Yews, Headingly, Leeds, England. '86
*Daly, Marcus, ... Butte, Mont. '87
*Dan, T., ... Micke Coal Mines, Chikugo, Japan. '88
*Danforth, A. H., ... 603 Boston Building, Denver, Colo. '82
*Daniels, Fred. H., ... 130 Lincoln Street, Worcester, Mass. '76
*Danziger, Jacob C., . . . Bethlehem Iron Co., So. Bethlehem, Pa. '93
*Darley, E. C., ... New Castle, Pa. '83
*Darling, William P., . S. F. Dept. General Electric Co., Lynn, Mass. '91
*Darlington, Henry, ... Pittsburgh, Pa. '90
*Darsie, James, ... 421 Wood Street, Pittsburgh, Pa. '93
Daubrée, Prof. A., ... Paris, France.
*Darton, N. H., . . . U. S. Geological Survey, Washington, D. C. '94
*Davenport, C. W., ... Erie, Pa. '81
*Davenport, Russell W., ... South Bethlehem, Pa. '77
**Davey, George, Negociacion de Trojes, Auganguco, Michoacan, Mexico. '91
*Davey, Thomas G, ... Harrietville, Victoria, Australia. '91
*David, W. M., ... Centreville, Bayonne City, N. J. '88
*Davidson, George M., . Care C. & N. W. Ry. C. Shops, Chicago, Ill. '81
*Davidson, Otto C., ... Commonwealth, Wis. '91
*Davidson, Walter B. M., . . . Sandhills, Betchworth, Surrey, Eng. '92
*Davis, A. B., . Care Koshland & Co., 222 Cal. Street, San Francisco, Cal. '89
*Davis, Britton, ... Corralitos, Chihuahua, Mexico. '90
*Davis, Prof. Floyd, . . New Mexico School of Mines, Sorocco, N. M. '83
†Davis, Frederick W., . . . 13 Burling Slip, New York City. '94
*Davis, George C., Bement Avenue, W. New Brighton, Staten Island, N. Y. '93
*Davis, Henry C., . . . 120 Broadway, Room 55, New York City. '81
*Davis, Harry J., ... Munhall, Pa. '94
*Davis, Henry E., ... Elkins, Randolph County W. Va. '94
*Davis, Lewis K., . National Lead Co., 1 Broadway, New York City. '93
*Davis, Louis M., 5 Union Court, Old Broad Street, London E. C., England. '84
*Davis, Morgan, Jr., ... Mt. Carmel, Pa. '93
*Davis, William C., ... P. O. Box 2371, Denver, Colo. '89
*Davis, William M., ... 1317 11th Avenue, Altoona, Pa. '91
*Davis, W. W., Jr., ... Care Crozer Iron Co., Roanoke, Va. '93
*Daw, John, Jr., . . Brooklands, Rosemont Road, Acton, W., England. '93
*Dawes, H. F., ... Englewood, N. J. '87
*Day, David T., . . U. S. Geological Survey, Washington, D. C. '87

*Dean, George A.,	Mingo Junction, Ohio.	'86
*De Camp, Alfred H.,	Trenton Junction, N. J.	'83
*De Camp, Clarence A.,	Boonton, N. J.	'90
*De Camp, W. S.,	35 Mount Morris Avenue cor. 124th St., New York City.	'75
**De Crano, E. G.,	5 Union Court, Old Broad Street, London, E. C., England.	'72
*De Deken, Albert,	Esperance, Seraing, Belgium.	'84
*DeKalb, Courtenay,	Room 224, 29 Broadway, New York City.	'92
*Deemer, John J.,	Chester, Pa.	'88
**Delano, Fred. A.,	Care C. B. & Q. R.R., Chicago, Ill.	'86
**Delano, Warren, Jr.,	1 Broadway, New York City.	'92
*Del Mar, Algernon,	16 Finsbury Circus, London, E. C., England.	'93
*Delprat, G. D.,	Campanas 15, Cordova, Spain.	'90
*Delrez, Theodore,	12 Chaussée d'Antin, Paris, France.	'92
*Demond, C. D.,	Great Falls, Mont.	'94
*Denny, G. A.,	211 Chapel Street, Pietermaritzburg, Natal, So. Africa.	'93
*Denton, Fred. W.,	Michigan Mining School, Houghton, Mich.	'92
*Denton, Prof. James E.,	Hoboken, N. J.	'88
*De Saulles, A. B.,	Lehigh Zinc and Iron Co., Bethlehem, Pa.	'71
*De Schweinitz, P. B.,	117 So. Linden Street, Bethlehem, Pa.	'82
*Desloge, John M.,	Desloge, Mo.	'81
*Devereux, James H.,	Aspen, Colo.	'89
*Devereux, W. B.,	Glenwood Springs, Colo.	'80
*Dewees, William H.,	9 North Thirteenth Street, Philadelphia, Pa.	'86
*Dewey, C. E.,	Clear Creek Mill, Georgetown, Colo.	'93
*Dewey, Fred. P.,	621 "F" Street, N. W., Washington, D. C.	'77
*Dewey, William P.,	180 Fifth Avenue, New York City.	'85
*Dickerman, A. L.,	Colorado Springs, Colo.	'88
*Dickerson, Winchester,	Olympia, Bath Co., Ky.	'87
*Dickert, Ferdinand,	P. O. Box 768, Salt Lake City, Utah.	'87
*Dickinson, Henry P.,	Room 73, 163 State Street, Chicago, Ill.	'93
*Dickinson, William E.,	Care N. R. Hart, Stamford, Conn.	'89
*Dickman, Robert N.,	71 Wade Building, Cleveland, Ohio.	'89
†Dimock, Clarence H.,	Windsor, Nova Scotia.	'86
*Dinkey, Charles E.,	Braddock, Pa.	'87
**D'Invilliers, E. V.,	711 Walnut Street, Philadelphia, Pa.	'82
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*Disston, Thomas S.,	Tacony, Philadelphia, Pa.	'86
*Doane, W. H.,	Care J. A. Fay & Co., Cincinnati, Ohio.	'90
*Dodge, James M.,	Nicetown, Philadelphia, Pa.	'94
*Dodge, Wallace H.,	Dodge Manufacturing Co., Mishawaka, Ind.	'84
*Dodson, Richard T.,	Arnot, Tioga Co., Pa.	'92
*Dominick, F. J.,	Room 14, 21 Cortlandt Street, New York City.	'82
*Donaldson, William J.,	Betz Building, Broad Street, Philadelphia, Pa.	'81
*Doney, De Witt C.,	National Smelting and Ref. Co., South Chicago, Ill.	'93
†Dorflinger, Charles H.,	White Mills, Pa.	'93
*Dorsey, E. B.,	949 Lexington Ave., New York City.	'79
*Doud, Edward,	Sheffield, Ala.	'91
**Dougherty, Clarence E.,	19 William Street, New York City.	'87
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*Downs, W. F., ... Dixon Crucible Co., Jersey City, N. J. '83
*Doxrud, Peter, ... Park Bros. & Co., Pittsburgh, Pa. '87
*Doyle, Pat., ... 19 Lall Bazar, Calcutta, India. '79
*Drake, Frank, ... 89 Appleton Street, Boston, Mass. '91
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*Drummond, John J., . . Radnor Forges, Province of Quebec, Canada. '93
*Drummond, Thomas J., ... Montreal, Canada. '94
*Duane, James, . . . Superintendent Dora Furnace, Pulaski. Va. '87
**Du Bois, Prof. Aug. Jay, ... New Haven, Conn. '75
*Du Bois, Howard W., ... Ishpeming, Mich. '94
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*Dudley, P. H., ... 80 to 82 Pine Street, New York City. '75
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*Dumble, Edwin T., ... Austin, Texas. '90
**Dumont, John M., ... Idaho Springs, Colo. '82
*Duncan, John, ... Calumet, Houghton Co., Mich. '80
*Duncan, M. M., ... Mancelona, Mich. '84
*Dunham, Lewis E., ... Ashland, Wis. '90
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*Edwards, Henry W., ... Commercial M. Co., Prescott, Ariz. '93
*Edwards, J. Warner, ... Rico, Colo. '76
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*Ferguson, E. M.,	Shady Side, Pittsburgh, Pa.	'78
†Ferguson, Samuel T.,	Minneapolis, Minn.	'84
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*Firmstone, H.,	Longdale, Alleghany Co., Va.	'75
*Fisher, Clark,	Trenton, N. J.	'71
*Fisher, John J.,	Allentown, Pa.	'81
*Fisher, Thomas,	Horatio, Jefferson Co., Pa.	'89
*Fisher, W. B.,	Virginia City, Mont.	'92
*Fiske, Henry G.,	45 E. Twenty-Second Street, New York City.	'90
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*Flaherty, Robert H.,	Iron Mountain, Mich.	'93
*Fleming, H. S.,	Care *Manufacturers' Record*, Baltimore, Md.	'84
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*Foote, F. H., ... Care Ill. Steel Co., South Chicago, Ill. '90
†Foote, Wallace T., Jr., ... Port Henry, N. Y. '92
*Forbes, Harry F., ... Rockford, Ill. '94
*Forbes-Leith, A. J., ... 46 Wall Street, New York City. '79
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*Ford, S. Alfred, . . Edgar Thomson Steel Co., Pittsburgh, Pa. '75
*Fordyce, John R., . . . 3634 Washington Avenue, St. Louis, Mo. '92
*Forker, D. M., ... Ala. Rolling Mill Co., Birmingham, Ala. '88
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*Forsyth, William, . . . Mech. Eng., C. B. & Q. R.R., Aurora, Ill. '84
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*Foster, Ernest Le Neve, . . . 2105 Lafayette Street, Denver, Colo. '75
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*Fowle, John C., ... Michigamme, Mich. '90
*Fowler, C. B, ... Leetonia, Ohio. '90
*Fowler, Percival, . . 16 St. Helen's Place, London, E. C., England. '88
*Fowler, Samuel S., ... Golden, B. C., Canada. '92
*Fox, James W., ... Big Stone Gap, Va. '91
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*Francis, W. Richardson, Caylloma Silver Mining Co., Caylloma, Peru, S. A. '90
**Francklyn, Charles G., . . 19 William Street, New York City. '80
*Franklin, Walter S., ... Sparrow's Point, Md. '79
*Frasch, H. A., . . . Care Grasselle Chemical Co., Cleveland, Ohio. '93
*Fraser, C. F., ... Hastings, Cambria Co., Pa. '92
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*French, Aaron, ... Pittsburgh, Pa. '94
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*Fricke, J. H., ... Hillsborough, N. M. '88
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*Fuller, Willard, . . . Union Rolling Mill Co., Cleveland, Ohio. '91
*Fulton, George Edward, ... Adelaide, South Australia. '91
*Fulton, John, ... Cambria Iron Co., Johnstown, Pa. '72
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*Gardner, George C., . . 311 First Nat. Bank Building, Chicago, Ill. '83
†Gardner, James P., . . 406 First Nat. Bank Building, Chicago, Ill. '87
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*Garside, George Wm., ... Juneau City, Alaska. '93
*Garthwaite, E. H., . . Esmeralda, Sierra Mojada, Coahuila, Mexico. '82
*Garvin, J. M., ... Rock Run, Cherokee Co., Ala. '92
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*Gilbert, E. J., ... Ely, Minn. '94
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*Glein, Fritz, ... Passaic Zinc Co., Jersey City, N. J. '92
*Glenn, William, ... 1348 Block Street, Baltimore, Md. '81
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*Goodell, E. E., ... P. O. Box 365, Pueblo, Colo. '90
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*Gordon, H. A., ... Wellington, New Zealand. '87
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*Hammer, Hakon,	367 High Street, Pottstown, Pa.	'89
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*Hammond, Isaac B.,	358 Dayton Street, Chicago, Ill.	'87
*Hammond, John Hays,	Crocker Building, San Francisco, Cal.	'81
*Hampton, William Huntley,	Wolf Creek, Josephine Co., Ore.	'90
**Hancock, Strangman,	P. O. Box 316, Johannesburg, Transvaal, So. Africa.	'89
*Hanna, George B.,	U. S. Assay Office, Charlotte, N. C.	'87
**Harden, E. B.,	411 N. Thirty-third Street, Philadelphia, Pa.	'73
**Harden, J. H.,	Phœnixville, Pa.	'71
*Hare, A. W.,	P. O. Box 381, Aspen, Colo.	'39
*Hardman, John E.,	Oldham Gold Mines, Nova Scotia.	'82
*Hardt, Anton,	Wellsboro, Pa.	'90
*Hardwick, Francis W.,	Firth College, Sheffield, England.	'89
*Harper, Joseph H.,	Butte, Mont.	'87
*Harrington, Dr. B. J.,	McGill College, Montreal, Canada.	'77
*Harris, George W.,	Elkhorn, W. Va.	'92
*Harris, W. J.,	Concho, Fayette Co., W. Va.	'71
*Harrison, G. W.,	E. & G. Brooke Iron Co., Birdsboro, Pa.	'92
*Harrison, Russell B.,	1 Broadway, New York City.	'77
*Hart, Prof. Edward,	Lafayette College, Easton, Pa.	'81
*Hartman, John M.,	1235 N. Front Street, Philadelphia, Pa.	'75
*Hartmann, A.,	Belleville, Ill.	'86
*Hartranft, S. S.,	Fort Washington, Montgomery Co., Pa.	'77
*Hartrick, John Standish,	Care H. T. Tisdall, "Rosbercon," Washington Street, Toorak, Melbourne, Australia.	'91
**Hartshorne, J.,	Stowe, Montgomery Co., Pa.	'73
*Hartzell, Dr. H. K.,	Allentown, Pa.	'92
*Harvey, Isaac A.,	Beech Creek, Clinton Co., Pa.	'92
*Harvey, James K.,	Guston, Ouray Co., Colo.	'90
*Haskell, Harry G.,	Wilmington, Del.	'94
*Haskell, J. A.	Care Repauno Chemical Co., Wilmington, Del.	'88
*Hasson, William F. C.,	104 Sutter Street, San Francisco, Cal.	'93
*Hastings, John B.,	Boise City, Idaho.	'86
*Hastings, Robert E.,	819 Filbert Street, Philadelphia, Pa.	'84
*Hathaway, Nathaniel,	New Bedford, Mass.	'88
**Hawker, E. W.,	Adelaide Club, Adelaide, So. Australia.	'92
*Hawkins, Edwin N.,	2143 Mt. Vernon Street, Philadelphia, Pa.	'90
*Hawkins, J. D.,	Aspen, Colo.	'93

*Haydon, J. C.,	Jeansville, Luzerne Co., Pa.	'74
*Hayes, C. Willard,	U. S. Geological Survey, Washington, D. C.	'92
*Hayes, George W.,	Lebanon, Pa.	'94
*Hazard, J. C.,	Macungie Furnaces, Catasauqua, Pa.	'92
†Hazard, R.,	Peace Dale, R. I.	'87
*Hazelton, Simeon C.,	Care Cia. Metalurgica Mexicana, San Luis Potosi, Mexico.	'91
*Headden, Prof. W. P.,	Rapid City, So. Dakota.	'89
*Heard, John, Jr.,	Care Messrs. Perier, Mercet & Co., 59 rue de Provence, Paris, France.	'83
*Hearne, Frank J.,	Wheeling, West Va.	'74
*Heath, George L.,	South Lake Linden, Mich.	'91
*Heckscher, A.,	45 Cedar Street, New York City.	'79
*Heckscher, Richard P.,	238 S. Third Street, Philadelphia, Pa.	'93
*Hedburg, Eric,	Gregg, Newton Co., Mo.	'94
*Hegeler, Edward C.,	La Salle, Ill.	'81
*Hegeler, Julius W.,	La Salle, Ill.	'92
*Heidenreich, E. Lee,	99 Metropolitan Block, Chicago, Ill.	'88
*Heimbach, August,	Butte and Boston Red. Works, Gunderson, Mont.	'93
†Heinze, F. August,	Box 428, Butte, Mont.	'89
*Helms, Albert,	8 Bridge Street, Sydney, New South Wales.	'89
*Hemphill, James,	Twelfth and Pike Streets, Pittsburgh, Pa.	'75
*Henderson, J. C.,	29 Broadway, New York City.	'91
*Henderson, Joseph J.,	Kingsbridge, N. Y.	'93
*Hendey, Arthur,	Guadalupe Y. Calvo, Chihuahua, Mexico.	'90
*Henley, James H.,	Granite Mountain Mining Co., Granite, Mont.	'90
*Hennin, Alphons,	Monongahela Furnaces, McKeesport, Pa.	'88
*Henning, Gustav C.,	Room 726, 5 Beekman St., New York City.	'86
*Henrich, Carl,	P. O. Box 7, Ducktown, Tenn.	'82
**Herndon, Edward L.,	Care H. Ames & Co., Springfield, Mo.	'82
*Herr, Hiero B.,	1623 Monadnock Building, Chicago, Ill.	'76
*Herreshoff, J. B. F.,	Laurel Hill, L. I., N. Y.	'86
*Hess, Abram,	Colbrook & Cornwall Anthracite Furnaces, Lebanon, Pa.	'92
*Hesse, Conrad E.,	508 A Street, S.E., Washington, D. C.	'90
*Hewett, G. C.,	1744 Corcoran Street, Washington, D. C.	'83
*Hewitt, Abram S.,	17 Burling Slip, New York City.	'71
*Hewitt, George H.,	707 State Street, Springfield, Mass.	'80
*Hewitt, R. A.,	Hackensack, N. J.	'88
*Hibbard, Henry D.,	Taylor Iron & Steel Co., High Bridge, N. J.	'79
*Higgin, Alfred J.,	So. Australia School of Mines, Adelaide, So. Australia.	'93
*Higgins, John Michael,	174 Barton Terrace, North Adelaide, So. Australia.	'91
*Hildreth, R. W.,	2 Wall Street, New York City.	'85
†Hildreth, Walter E.,	Broadway and Prince Street, New York City.	'75
*Hill, Frank A.,	1011 So. Forty-eighth Street, Philadelphia, Pa.	'83
*Hill, H. C.,	P. O. Box 1040, Salt Lake City, Utah.	'86
*Hill, Robert T.,	Cosmos Club, Washington, D. C.	'92
*Hillard, Charles, J.,	P. O. Box 282, Pittsburgh, Pa.	'88
*Hilles, Joseph T.,	Pottstown Iron Co., Pottstown, Pa.	'92
**Hinchman, Charles S.,	208 S. Fourth Street, Philadelphia, Pa.	'79
*Hines, Samuel,	Scranton, Pa.	'87

*Hinton, Francis, . . 151 New Insurance Building, Milwaukee, Wis. '91
*Hitchcock, Prof. C. H., . . . State Geologist, Hanover, N. H. '79
*Hitchcock, E. A., . . . Crystal Plate Glass Co., St. Louis, Mo. '80
*Hoatson John, ... Box 1010, Butte, Mont. '91
*Hoatson, Thomas, ... Calumet, Mich. '80
*Hoblitzell, J. J., ... Meyersdale, Pa. '93
*Hobson, John B., ... Quesnelle Forks, British Columbia. '92
†Hobson, Thomas, ... 220 S. 4th Street, Philadelphia, Pa. '92
**Hodge, Arthur, . Care James Floyd, St. Anstell, Cornwall, England. '89
*Hodge, J. M., ... Big Stone Gap, Va. '88
*Hodges, A. D., Jr., ... P. O. Box 1857, Boston, Mass. '84
*Hodges, A. B. W., . . Rio Grande Smelting Co., Socorro, N. Mex. '89
*Hodges, H. B., ... B. & O. R. R., Baltimore, Md. '89
*Hodgson, Thomas, . . . 257 Washington Street, Buffalo, N. Y. '85
Hoefer, Prof. Hanns, ... Leoben, Austria.
*Hoefer, Eugene, . 2 Bayley St., Bedford Sq., London, W. C., England. '88
*Hoffman, John W., ... Bullitt Building, Philadelphia, Pa. '76
*Hoffman, William D., ... Brewster, N. Y. '91
*Hoffman, William H., ... Brewster, N. Y. '91
*Hoffstot, F. N., ... 238 Wood Street, Pittsburgh, Pa. '82
*Hofius, W. D., ... Trinidad, Colo. '90
*Hofman, Dr. H. O., . . Mass. Institute of Technology, Boston, Mass. '82
*Hofmann, Ottokar, ... Cusihuiriachic, Chihuahua, Mexico. '84
*Holbrook, F. N., . . . P. O. Box 395, Tarrytown, New York. '75
†Holbrook, Levi, ... P. O. Box 536, New York City. '78
†Holden, E. F., ... 520 W. Onondaga Street, Syracuse, N. Y. '87
*Holden, L. E., ... P. O. Box 1027, Salt Lake City, Utah. '86
*Holgate, Thomas E., . . 146 Blackburn Road, Darwen, England. '92
*Hollenbeck, J. I., ... Audenried, Carbon Co., Pa. '82
*Hollerith, Herman, . . . 501 F Street, Washington, D. C. '83
*Hollis, H. L., ... 1232 Rookery, Chicago, Ill. '85
*Hollow, J. T., ... Zalathna, Transylvania, Austro-Hungary. '92
*Holloway, J. F., ... 86 Liberty Street, New York City. '75
*Holman, F. C., . . Cor. Polk and Filbert Streets, San Francisco, Cal. '81
*Holmboe, L., ... 1034 Rookery, Chicago, Ill. '87
†Holt, J. C., ... Antrim Iron Co., Grand Rapids, Mich. '92
*Holt, M. B., ... Colo. Smelting Co., Pueblo, Colo. '89
*Holthoff, H. C., ... Buena Vista, Colo. '89
*Honnold, William L., ... Hibbing, St. Louis Co., Minn. '93
*Hooker Howard M., . . Monongahela Furnaces, McKeesport, Pa. '92
*Hooker, W. A., ... Room 61, 90 Broadway, New York City. '80
*Hooper, Edward, ... { Care J. H. Hooper, College Precincts, Worcester, England. '88
*Hooper, William, ... Ticonderoga, N. Y. '78
*Hopke, Theodore M., ... { Pittsburgh Red. Co., New Kensington, Westmoreland Co., Pa. '88
*Hopkins, George A., ... Swissvale, Allegheny Co., Pa. '94
*Horwood, E. J., Broken Hill, Prop. Co., Broken Hill, New South Wales. '93
*Hosie, James P., ... 1535 Sanderson Aveuue, Scranton, Pa. '89
*Hosking, George Francis, . . . Bendigo, Otago, New Zealand. '91
*Hoskins, William, ... 81 S. Clark Street, Chicago, Ill. '87

*Hotchkiss, Jed., ... Staunton, Va. '79
*Houston, C. B., ... Thurlow, Delaware Co., Pa. '83
*Houston, T. E., ... Elkhorn, W. Va. '92
*Howald, Ferdinand, . . . Rush Run, Fayette Co., W. Va. '84
*Howard, Thomas, . . . Twelfth and Papin Streets, St. Louis, Mo. '86
*Howe, C. F., ... 631 Chamber of Commerce, Duluth, Minn. '86
†Howe, Epenetus, . . Esmeralda, Sierra Mojada, Coahuila, Mexico. '86
*Howe, Frank P., . { Care Wharton & Co., Twenty-fifth Street and Washington Avenue, Philadelphia, Pa. '79
*Howe, Henry M., . . . 287 Marlborough Street, Boston, Mass. '71
*Howell, Benjamin P., . . . P. O. Box 383, Knoxville, Tenn. '84
*Howell, John, Broken Hill, Prop. Co., Broken Hill, New South Wales. '93
*Hubbell, J. C., ... Ellensburgh, Kittitass Co., Wash. '87
*Huber, H., ... K. C. R. & S. Co., Argentine, Kas. '82
**Hughes, A. D., ... 90 Cannon Street, London E. C., England. '92
*Hughes, Benjamin, ... 1201 Washburn Street, Scranton, Pa. '87
*Hughes, Godfrey, . Boston and Montana Smelter, Great Falls, Mont. '92
*Hughes, Herbert W., ... Dudley, England. '87
*Hughes, Thomas E., ... 26 7th Avenue, Pittsburgh, Pa. '92
*Huhn, E. C. O., ... Maybert, Nevada Co., Cal. '86
†Hulick, William H., . . . 160 Broadway, New York City, '82
*Hulst, Nelson P., ... 300 Knapp Street, Milwaukee, Wis. '76
*Humbert, George J., ... P. O. Box, 13 Norristown, Pa. '88
*Humphrey, Charles, ... P. O. Box 135, Bingham, Utah. '85
*Humphrey, George S., . West New Brighton, Staten Island, N. Y. '84
*Humphreys, Alexander C., . . Drexel Building, Philadelphia. Pa. '85
*Hungerford, W. S., . . . Care W. Ames & Co., Jersey City, N. J. '82
*Hunicke, H. August, . . . 1219 Mississippi Avenue, St. Louis, Mo. '83
*Hunsiker, Millard, ... Duquesne Club, Pittsburgh, Pa. '89
*Hunt, Alfred E., 701 Ferguson Building, 321 Third Avenue, Pittsburgh, Pa. '79
**Hunt, C. W., ... 45 Broadway, New York City. '91
*Hunt, Fred. F., ... 77 Pine Street, New York City, '80
*Hunt, Joseph, . . . Third and Walnut Streets, Allentown, Pa. '71
*Hunt, M. R., ... Ashland, Wis. '96
*Hunt, Robert W., ... 631 The Rookery, Chicago, Ill. '74
*Hunt, William P., Jr., . . . 57 Foundry Street, Boston, Mass. '88
*Huntington, Fred. W., ... Bartow, Polk Co., Fla. '85
*Huntley, Dwight B., ... Mullan, Idaho. '92
*Hutchinson, E. S., ... Maybeury, West Va. '80
*Hutchinson, Randolph B., Care Sombrerete Mining Co., Zacatecas, Mexico. '91
*Hutton, Fred. R., . . . 296 Lexington Avenue, New York City. '75
*Hyde, George Preston, ... Illinois Steel Co., Joliet, Ill. '93

*Ihlseng, Axel O., ... Carthage, Mo. '82
*Ingall, Elfric D., . . Geological Survey of Canada, Ottawa, Canada. '89
*Ingalls, Walter Renton, . . . 12 Old Slip, New York City. '91
*Ingersoll, George U., ... Silverton, Colo. '93
†Ingham, William A., . . 320 Walnut Street, Philadelphia, Pa. '72
*Inglis, Alexander, ... Cloverport, Ky. '88
*Inman, Alvin L., ... Plattsburgh, N. Y. '76
*Inman, T. L., Guisberg Gold Mfg. Co., Johannesburg, Transvaal, So. Africa. '93

*Ireland, Thomas A., . . 1191 Wilson Avenue, Cleveland, Ohio. '90
*Irwin, William A. W., . G. F. P. Co., Lucknow, New South Wales. '92

*Jabs, Asmus, ... Whylen, Baden, Germany. '88
*Jackson, Frederick M., . . . Brookwood, Tuscaloosa Co., Ala. '93
*Jackson, J. Howard, Gen. Mgr. Spur Co., Lawrence, Otago, New Zealand. '93
*Jacobus, David S., ... Stevens Institute, Hoboken, N. J. '88
*James, Reese, ... Carnegie Bros. & Co., Braddock, Pa. '79
*James, Dr. Walter M., . . 1125 Spruce Street, Philadelphia, Pa. '84
*Jamme, George, . . Dayton Coal and Iron Co., Limited, Dayton, Tenn. '79
*Janeway, John H., Jr., . Care of John Roebling Sons, Trenton, N. J. '86
*Janin, Alexis, . . 211 Sansome Street, Room 6, San Francisco, Cal. '85
*Janin, Henry, . . . 20 East Thirty-fifth Street, New York City. '72
*Janin, Louis, . . 211 Sansome Street, Room 6, San Francisco, Cal '72
*Janney, Morris P., . . Cor. York and Walnut Streets, Pottstown, Pa. '74
*Jaques, W. H., ... South Bethlehem, Pa. '90
*Jardine, John A., ... Hartranft, Tenn. '93
*Jaycox, J. M., ... 52 S. Thayer Street, Ann Arbor, Mich. '88
*Jenkins, George E., ... Dover, N. J. '89
*Jenks, A. W., . . . Balback Smelting and Ref. Co., Newark, N. J. '87
*Jenks, William, ... Albuquerque, New Mex. '87
*Jenney, Walter P., . . . P. O. Box 397, Rapid City, So. Dakota. '74
*Jennings, E. P., ... Ironwood, Mich. '76
*Jennings, Hennen, . P. O. Box 149, Johannesburg, Transvaal, So. Africa. '84
*Jennings, Robert E., . West Bergen Steel Works, Jersey City, N. J. '91
*Jermyn, John, ... 119 Wyoming Avenue, Scranton, Pa. '87
*Jessop, William Henry, . . . { P. O. Box 213, Johannesburg, Transvaal, So. Africa. '92
*Jewell, Edward E., . . . 3535 Champlain Street, Chicago, Ill. '84
*Jewett, Eliot C., ... P. O. Box 576, St. Louis, Mo. '81
*Johns, L. W., ... Bessemer, Ala. '85
*Johnson, Charles H., ... New Castle, Pa. '93
*Johnson, E. W., . . . Care Colorado Smelting Co., Pueblo, Colo. '93
*Johnson, Frank M., ... Quartz Creek Mill, Pitkin, Colo. '87
*Johnson, Guy R., ... Longdale, Alleghany Co., Va. '89
*Johnson, Isaac G., ... Spuyten Duyvil, New York City. '79
*Johnson, J. E., ... Longdale, Alleghany Co., Va. '80
*Johnson, Orlando S., ... Scranton, Pa. '91
*Johnston, Edgar D., ... Connersville, Ind. '91
*Johnston, J. Howard, . Care Bacchus & Johnston, Lima, Peru, S. A. '87
*Jolliffe, William, ... Buchanan, Va. '81
*Jones, B. F., . . . Jones & Laughlin's Works, Pittsburgh, Pa. '78
*Jones, Clemens, ... 433 Northampton Street, Easton, Pa. '86
*Jones, Edward, ... Olyphant, Pa. '87
*Jones, Edwards P., . . . Gold Bullion Mining Co., Clifton, Ariz. '93
*Jones, Frederick D., ... Youngstown, Ohio. '93
*Jones, James F., . . . 4056 Chestnut Street, Philadelphia, Pa. '88
*Jones, John T., ... Iron Mountain, Mich. '80
*Jones, Ralph A., ... Alpena, Mich. '89
*Jones, T. C., ... Iron Gate, Va. '81
*Jones, Thomas D., ... Hazleton, Pa. '75

*Jones, Thomas J.,	Bertha Zinc Mines, Pulaski, Va.	'92
*Jones, W. Larimer,	Jones & Laughlin, Ltd., Pittsburgh, Pa.	'88
**Jones, Washington,	1632 N. Fifteenth Street, Philadelphia, Pa.	'81
*Jopling, Jas. E.,	Marquette, Mich.	'84
†Jopling, Reginald F.,	842 Willson Avenue, Cleveland, Ohio.	'89
*Joüet, C. H.,	Roselle, N. J.	'83
*Jousselin, A. Leon,	28 rue des Petits Hotels, Paris, France.	'88
*Judd, Henry A.,	New London, Stanley Co., N. C.	'90
*Judkins, Charles A.,	P. O. Box 5, Leadville, Colo.	'89
*Judson, John N.,	2201 Park Avenue, St. Louis, Mo.	'84
†Julian, Frank,	Illinois Steel Co., South Chicago, Ill.	'81
*Kada, Teichi,	Chiofu, Nagato, Yamaguchiken, Japan.	'88
*Kanda, Reji,	9 Second Street, Tokio, Japan.	'93
*Karrick, L. C.,	Salt Lake City, Utah.	'86
*Kasahara, Washitaro,	Care Takato & Co., Tokio, Japan.	'90
*Kaufman, Charles,	Care Gambetta Mining Co., Grub Gulch, Cal.	'89
*Kaufman, William M.,	Sheridan, Pa.	'92
*Kawai, Yasushiro,	Care of Poronai Coal Mine and R.R. Co., Hokkaido, Japan.	'91
*Keatley, Edwin M.,	Coopers, W. Va.	'92
*Kebler, Eliot A.,	Fern Bank, Hamilton Co., Ohio.	'84
*Kebler, Julian A.,	701 Boston Building, Denver, Colo.	'85
*Keeley, Frank J.,	421 Chestnut Street, Philadelphia, Pa.	'92
*Keeley, Jerome,	421 Chestnut Street, Philadelphia, Pa.	'76
*Kedzie, George E.,	Ouray, Colo.	'88
**Keep, W. J.,	753 Jefferson Avenue, Detroit, Mich.	'88
*Keighley, Fred. C.,	Uniontown, Pa.	'88
*Keller, Arthur H.,	Durango, Colo.	'83
*Keller, Hermann A.,	P. O. Box 233, Butte, Mont.	'81
*Kelley, Walter S.,	P. O. Box 361, Helena, Mont.	'89
*Kellogg, John S., Jr.,	Illinois Steel Company, South Chicago, Ill.	'93
*Kelly, William,	Vulcan, Mich.	'90
*Kemler, W. H.,	Ashland, Ky.	'90
*Kemp, James F.,	Columbia College, Forty-ninth Street, New York City.	'91
*Kemp, William,	Troy, N. Y.	'83
*Kempton, C. W.,	Oro Blanco, Ariz.	'75
*Kennedy, Hugh,	Etna, Allegheny Co., Pa.	'81
*Kennedy, John S.,	Chambersburg, Pa.	'81
*Kennedy, Julian,	702 Hamilton Building, Pittsburgh, Pa.	'79
*Kennedy, O. W.,	H. C. Fricke Coke Co., Scottdale, Pa.	'93
*Kennedy, William,	Austin, Texas.	'91
*Kent, Joseph C.,	Phillipsburg, N. J.	'72
*Kent, R.,	Burnham, Mifflin Co., Pa.	'84
*Kent, William,	Passaic, N. J.	'76
**Kent, William St. G.,	Phillipsburg, N. J.	'72
*Kenyon, Enoch,	Ward, Boulder Co., Colo.	'92
Kerl, Dr. Bruno,	Wichmannstrasse 1, Berlin, Germany.	
*Kerr, David G.,	Wilkinsburg, Pa.	'86
*Kerr, Mark B.,	Tumaco, Colombia, S. A.	'90
†Kerr, Thomas B.,	120 Broadway, New York City.	'92

*Ketchum, Landon, ... Saugatuck, Conn. '89
*Keyes, W. S., ... Pacific Union Club, San Francisco, Cal. '72
*Keyser, William, ... Keyser Building, Baltimore, Md. '92
*Kimball, Hiram, ... City Forge, Cleveland, Ohio. '82
*King, Charles C., Care C. W. Hunt & Co., 45 Broadway, New York City. '92
**King, Charles F., ... Steelton, Pa. '80
*King, Thomas M., ... Cor. Green and Coulter Sts., Germantown, Philadelphia, Pa. '82
*King, Tom Cobb, ... 1625 Willmer Street, Anniston, Ala. '90
*Kingsbury, Joseph T., . 517 Fourth East Street, Salt Lake City, Utah. '88
*Kingsley, J. Cook, ... Santa Rosa, Capan, Honduras, C. A. '82
†Kirby, Edmund B., ... P. O. Box 2234, Denver, Colo. '84
*Kirchhoff, Charles, ... 96 Reade Street, New York City. '75
*Kitsunesaki, T., . Care I. Furnkawa, 107 Seto Monocho, Tokio, Japan. '91
*Klepetko, Frank, ... Great Falls, Mont. '80
*Knapp, E. E., ... Colorado Fuel and Iron Co., Pueblo, Colo. '92
*Knapp, George F., ... Lock Box 95, Sparrow's Point, Md. '87
†Knapp, S. A., Jr., ... Hawthorne, Nev. '85
*Knight, Albert B., ... Butte, Mont. '84
*Knight, F. H., ... Chain Dam, Easton, Pa. '90
*Knoertzer, Henri, . . Le Nickel, 13 rue Lafayette, Paris, France. '92
*Knox, H. H., ... Sterlington, Rockland County, N. Y. '92
*Koberle, Albert, ... P. O. Box 387, St. Louis, Mo. '91
*Koch, Walter E., . Care Spang Steel and Iron Co., Sharpsburg, Pa. '86
*Koehler, Walter J., ... Broken Hill, New South Wales. '91
*Koenig, Prof. George A., . Michigan Mining School, Houghton, Mich. '74
*Kolbe, Carl W., ... Midland, Crawford Co., Mo. '90
*Kondo, R., ... 7 Seto Monocho Nihonbashi, Tokio, Japan. '88
*Krabler, Emil, ... Altenessen, Germany. '91
†Kraft, John E., ... 105 Seminary Avenue, Chicago, Ill. '86
*Krom, S. R., ... 115 Plymouth Street, Jersey City, N. J. '85
*Kunhardt, Wheaton B., . . . 32 Beaver Street, New York City. '80
*Kuntzen, Theodor, . Care D. & D. Sm. Co., Deadwood, South Dakota. '90
†Kunz, George F., Care Tiffany & Co., 11 Union Square, New York City. '88
*Kurtz, Edward L., ... 17 Pittsburgh Street, Newcastle, Pa. '94
*Kurtz, Henry M., ... Clearfield, Pa. '93
*Kuwabara, Masa, ... 26 Yokobori-Itschome, Osaka, Japan. '88

*Lacombe, Charles F., ... P. O. Box 1545, Denver, Colo. '85
*Ladd, Story B., ... 412 5th Street, Washington, D. C. '91
*Lamb, William, ... Norfolk, Va. '94
*Lamborn, Dr. Robert H., . . . 32 Nassau Street, New York City. '76
*Lamm, Oscar F., ... Lansing, Kansas. '87
*Lammers, Theodore L., 431 Chamber of Commerce Building, Duluth, Minn. '93
*Landig, O. O., ... Care Buffalo Furnace Co., Buffalo, N. Y. '93
**Landis, Edward K., ... Philadelphia Testing Laboratory, 208 So. Fourth Street, Philadelphia, Pa. '82
*Landis, H. K., ... Missouri School of Mines, Rolla, Mo. '94
*Lane, J. S., ... 408 Oak Park Avenue, Oak Park, Ill. '80
*Lang, Herbert, ... 812 Tacoma Avenue, Tacoma, Wash. '87
*Lang, William, ... Dunbar Furnace, Dunbar, Pa. '92

†Langcloth, J., ... 80 Wall Street, New York City. '90
*Langdon, D. W., Jr., ... University Club, Cincinnati, Ohio. '90
*Langdon, N. M., ... Everett, Pa. '81
*Langdon, P. D., ... "The Hill," Augusta, Ga. '87
*Langguth, Werner, ... Yaquina City, Ore. '91
*Langley, John W., ... 845½ Fairmount Street, Cleveland, Ohio. '90
*Lanning, John G., ... 52 Newport Street, Dorchester, Mass. '93
**Larnach, William J. M., . "The Camp," Dunedin, New Zealand. '87
*Larsson, Per., ... Norway, Mich. '86
*La Rue, W. G., ... 523 W. Second Street, Duluth, Minn. '88
*Lash, Horace W., ... Carbon Iron Co., Pittsburgh, Pa. '88
*Lathrop, M. A., ... San Ardo, Cal. '89
*Lathrop, W. A., ... Wilkes-Barre, Pa. '83
*Lauder, George, ... 48 Fifth Avenue, Pittsburgh, Pa. '78
*Laureau, L. G., . . 60 Washington Square, South, New York City. '78
*Lavagnino, G., ... P. O. Box 550, Salt Lake City, Utah. '85
*Law, John B., ... Pittston, Pa. '91
*Lawall, Elmer H., Lehigh and Wilkes-Barre Coal Co., Wilkes-Barre, Pa. '90
*Lawrence, Benjamin B., ... P. O. Box 1545, Denver, Colo. '82
*Lawrence, Charles E., ... Amasa, Iron Co., Mich. '93
*Lawrence, H. L., 3 Maxilla Gardens, N. Kensington, London, W., England. '93
*Lawrence, W. L., ... Scranton, Pa. '83
*Lawton, Charles L., ... Palmer, Mich. '92
*Lawton, James E., . . . Lock Box 11, Cumberland Gap, Tenn. '91
*Lay, H. C., ... Telluride, Colo. '89
*Leaf, Richard T., ... Leesport Iron Co., Reading, Pa. '92
†Leary, Daniel J., . . 43 East Twenty-fifth Street, New York City. '81
*Leavitt, E. D., ... 2 Central Square, Cambridgeport, Mass. '76
*Le Boutillier, Clement, ... High Bridge, N. J. '91
*Leckie, Robert G., Londonderry Iron Co., Ltd., Londonderry, Nova Scotia. '79
*Leckie, R. G. E., ... Torbrook Mines, Nova Scotia. '91
*Ledoux, Albert R., ... 9 Cliff Street, New York City. '89
†Ledyard, T. D., ... 57 Colborne Street, Toronto, Canada. '90
*Lee, Arthur H., ... P. O. Box 481, Scranton, Pa. '87
*Lee, J. Henry, . . . Nat. Marine Bank Building, Baltimore, Md. '90
*Lee, Richard Henry, Jr., ... Lewistown, Pa. '83
*Lee, Richard Henry, . . 228 S. Seventh Street, Philadelphia, Pa. '76
†Leech, E. O., ... Director of the Mint, Washington, D. C. '90
*Leete, William McNeil, . Minas Prietas, Torres Station, Sonora, Mexico. '91
*LeFevre, Henry Francis, ... Panama, Colombia, S. A. '93
*LeFevre, Solomon, ... Forest Glen, Ulster Co., N. Y. '93
†Leggat, John A., ... Butte, Mont. '87
*Leggett, Thomas H., . . Care Standard Cons. Mining Co., Bodie, Cal. '82
*Lehman, A. E., ... 711 Walnut Street, Philadelphia, Pa. '83
*Lehman, George M., . . . Gt. Falls W. P. Co., Weldon, N. C. '86
*Lehmann, Gustavus W., . . . 735 Spruce Street, Philadelphia, Pa. '91
*Leisenring, E. B., . . . 137 So. Second Street, Philadelphia, Pa. '82
*Leisenring, Walter, ... Sandy Run, Luzerne Co., Pa. '91
*Leiter, T. Benton, ... Sheridan, Madison Co., Mont. '93
*Lennig, Nicholas, . . . 112 S. Front Street, Philadelphia, Pa. '82
*Lentz, W. O., ... Mauch Chunk, Pa. '85

*Leonard, Henry R.,	257 S. Fourth Street, Philadelphia, Pa.	'92
*Leonard, William A.,	West Wareham, Mass.	'89
Lesley, Prof. J. P.,	1008 Clinton Street, Philadelphia, Pa.	
*Lessig, George B.,	351 High Street, Pottstown, Pa.	'92
*Letts, Robert F.,	334 Union, Lima, Peru, S. A.	'91
**Levat, David,	9 rue de Printemps, Paris, France.	'87
*Lewald, E. A.,	Fishkill-on-Hudson, N. Y.	'87
†Lewis, Albert,	Bear Creek, Luzerne Co., Pa.	'91
*Lewis, James F.,	23 Park Place, New York City.	'75
*Lewis, Sir William Thomas,	Mardy, Aberdare, Wales.	'91
*Lidgey, Ernest,	Myra Lynn Sturt Street, Ballarat, Victoria, Australia.	'93
*Lidner, Pei Gustaf,	Shaw, W. Va.	'91
*Lihme, I. P.,	27 Tift Avenue, Cleveland, Ohio.	'92
*Lilienberg, N.,	150 Broadway, New York City.	'84
*Linderman Robert P.,	South Bethlehem, Pa.	'60
*Lindsay, William W.,	Germantown Junction, Philadelphia, Pa.	'89
*Lindsley, James G.,	Rondout, N. Y.	'89
*Lindsley, Stuart,	Orange, N. J.	'82
*Lippincott, J. Evans,	Alexandria, Ind.	'85
*Little, Theodore, Jr.,	Aspen, Colo.	'87
*Livingston, Charles H.,	3555 Marion Street, Denver, Colo.	'89
*Lloyd, Richard L.,	208 W. Copper Street, Butte, Mont.	'93
*Loane, William E.,	P. O. Box 48, Aspen, Colo.	'91
*Locke, Bradford H.,	Central City, Colo.	'88
*Locke, Franklin B.,	1033 Exchange Building, State Street, Boston, Mass.	'89
*Locke, Joseph M.,	58 W. Third Street, Cincinnati, Ohio.	'87
*Lodge, J.,	South Pittsburg, Tenn.	'88
*Lodge, Richard W.,	1423 Washington Street, Boston, Mass.	'83
*Lombard, Thomas R.,	31 Broadway, New York City.	'86
*Long, John C.,	Carlisle, Pa.	'81
*Long, William,	Dunbar Furnace Co., Dunbar, Pa.	'92
*Long, William H.,	Fairlee, Vermont.	'82
*Longacre, Orleans,	Spuyten Duyvil, New York City.	'81
*Longnecker, G. A.,	Mechanicsburg, Pa.	'83
*Longyear, E. J.,	Hibbing, Minn.	'92
*Loomis, Burdett,	Hartford, Conn.	'91
*Lord, Prof. N. W.,	Ohio State University, Columbus, Ohio.	'75
*Lord R. F.,	21 Ulster Place, Port Jervis, N. Y.	'82
*Lord, William B.,	68 Wall Street, New York City.	'92
**Louis, David A.	77 Shirland Gardens, London W., England.	'91
*Louis, Henry,	Heightleigh, Launceston, Cornwall, England.	'88
*Love, William J.,	Embreville, Washington Co., Tenn.	'91
*Lovejoy, Ellis,	Union Furnace, Hocking Co., Ohio.	'86
*Loveland, William L.,	Care Fraser & Chalmers, Union St., Chicago, Ill.	'87
*Ludlow, Edwin,	Hartshorne, Indian Territory.	'93
*Lukens, Jawood,	Conshohocken, Pa.	'84
*Lundbohm, Hjalmar,	Geological Survey, Stockholm, Sweden.	'92
*Luther, R. C.,	Pottsville, Pa.	'84
*Luttgen, Eberhard,	Care Keasbey & Mattison, Ambler, Pa.	'85

*Lychenheim, Jacob, ... Swedeland, Montgomery Co., Pa. '89
*Lyle, Capt. David A., . . . P. O. Box 1606, Philadelphia, Pa. '88
**Lyman, Benjamin Smith, . . 708 Locust Street, Philadelphia, Pa. '71
††Lyman, Frank, ... 50 Remsen Street, Brooklyn, N. Y. '77

*McCalley, Henry, ... University, Ala. '88
†McCallum, Wm. H., New Glen Echo Mills, Wayne Junct'n, Philadelphia, Pa. '84
*McCandless, E. V., ... Pittsburgh, Pa. '79
*McCann, Ferdinand, ... Lenado, Pitkin Co., Colo. '89
*McCay, Dr. L. W., ... Princeton College, Princeton, N. J. '85
*McClellan, Arthur, ... Drifton, Luzerne Co., Pa. '71
*McClurg, James A., ... Meadville, Pa. '92
*McClure, Robert J., . Room 65, C. B. & Q. R.R. Offices, Chicago, Ill. '84
*McClure, Samuel, ... Sharon, Mercer Co., Pa. '91
*McConnell, Nevin, ... Munhall, Allegheny Co., Pa. '94
*McCormack, G. B., . . . 915 Seventeenth Street, Birmingham, Ala. '91
*McCormick, Henry, ... Harrisburg, Pa. '74
*McCormick, Henry, Jr., . . . 223 Market Street, Harrisburg, Pa. '92
*McCormick, V. C., ... 223 Market Street, Harrisburg, Pa. '94
*McCreath, Andrew S., . . . 223 Market Street, Harrisburg, Pa. '75
*McCrery, Charles, ... Bessemer Steel Works, Troy, N. Y. '89
*McCulloch, E. A., ... Glencoe, Baltimore Co., Md. '80
*McCullough, C. H., Jr., . . . Illinois Steel Co., So. Chicago, Ill. '93
*McCulloch, Richard, . . 1521 E. Grand Avenue, St. Louis, Mo. '91
*McCune, J. H., ... Avondale, Ala. '87
*McDermott, Walter, . . . 23 Bucklersbury, London, England. '74
*McDonald, J. C. . . . . Country Harbor Mines, Nova Scotia. '94
*McDonald, Samuel, ... P. O. Box 323, Duquesne, Pa. '85
*McDonald, Thomas, ... Ohio Steel Co., Youngstown, Ohio. '90
*McDougall, George, . . . 85 Osborne Street, Montreal, Canada. '93
**McDowell, F. H., ... 66 Cortlandt Street, New York City. '78
*McElroy, Karl P., . . U. S. Dept. Agriculture, Washington, D. C. '92
*McGee, W. J., . . . U. S. Geological Survey, Washington, D. C. '92
*McGinnes, T. F., ... Danville, Pa. '93
*McGonagle, William A., . . . Two Harbors, Lake Co., Minn. '87
*McHose, A. A., ... Norristown, Pa. '90
*McIlvain, E. M., . . Bethlehem Iron Co., South Bethlehem, Pa. '86
*McIlvain, William R., ... Reading, Pa. '92
*McKee, John F., ... Baker Mines, Carroll Co., Va. '92
†McKeen, James, ... Tilly Foster, N. Y. '90
*McKeown, S. W., ... Youngstown, Ohio. '83
*McKill, William, ... Glen Jean, Fayette Co., W. Va. '94
**McKillop, John, . . { Care The Straits Settlements Trading Co., Limited, Singapore, Strait Settlements. '93
†McKinney, R. C., ... Hamilton, Ohio. '86
*McKinnon, G. W. W., B. H. Proprietary Co., Broken Hill, New South Wales. '93
*McLanahan, J. King, ... Hollidaysburgh, Pa. '81
*McLeavy, John, ... Helvetia, Clearfield Co., Pa. '75
*McLennan, J. S., ... Sydney, Cape Breton, Nova Scotia. '85
*McLeod, H. S., ... Troy, N. Y. '83
*McLure, Charles D., . Room 136, Laclede Building, St. Louis, Mo. '88

*McNair, Thomas S.,	Hazleton, Pa.	'71
*McVichie, D.,	Iron Belt, Wis.	'91
*Maas, Philip S.,	1228 W. College Avenue, Philadelphia, Pa.	'92
*Macandrew, Harold,	Adelaide, So. Australia.	'93
*MacArthur, John S.,	13 W. Scotland Street, Kinning Park, Glasgow, Scotland.	'92
*Macco, Heinz,	Siegen, Germany.	'92
*MacDonald, Bernard,	211 North Main Street, Butte, Mont.	'89
*Macdonald, Charles,	1 Broadway, New York City.	'75
*Macduff, George,	Waverly, Nova Scotia.	'91
*Macfarlane, G.,	The Commerce Building, Louisville, Ky.	'86
*Macfarlane, Thomas,	Inland Revenue Department, Ottawa, Canada.	'89
†MacGinniss, John S.,	San Juan, Argentine Republic, S. A.	'93
*MacGonigle, John N.,	P. O. Box 181, St. Augustine, Fla.	'93
*Mack, Thomas A.,	99 N. Fourth Street, Cincinnati, Ohio.	'88
*Mackay, Angus,	Care Fraser & Chalmers, Chicago, Ill.	'87
*Mackay, Walter,	P. O. Box 224, Butte, Mont.	'87
*Mackenzie, G. S.,	Care Sydney Tin Smelting Co., Pyrmont, Sydney, New South Wales.	'87
*MacNauhton, James,	248 State Street, Albany, N. Y.	'93
*MacNaughton, James,	Iron Mountain, Mich.	'90
*Macnutt, C. H.	Amethyst P. O., Creede Camp, Colo.	'90
*Macomber, Squire H.,	678 W. Monroe Street, Chicago, Ill.	'91
*Magruder, William T.,	Vanderbilt University, Nashville, Tenn.	'88
*Mahony, Arthur S. J.,	166 E. 64th Street, New York City.	'88
*Malcolmson, James,	Mexico Ore Co., Apartado 94, Pachuca, Mexico.	'90
*Mallman, John,	P. O. Box 534, Duluth, Minn.	'87
*Manley, Henry L.,	23 E. Fourth Street, South Bethlehem, Pa.	'93
*Mannesmann, Reinhart,	1 Broadway, New York City, and Remscheid, Germany.	'94
*Mannesmann, Robert,	434 Fourth Avenue, New York City.	'90
*Mannheim, H. C.,	254 Cumberland Street, Brooklyn, N. Y.	'89
*Mannheim, P. A. L.,	United Smelting Refining Co., East Helena, Mont.	'89
**Manzavino, Nicholas,	Care Denis Marcopulo, Smyrna, Turkey.	'90
*Marié, Leon,	203 Broadway, New York City.	'85
*Markham, Alfred,	Sun Building, St. John, N. B., Canada.	'82
*Markle, Alvan,	Hazleton, Pa.	'85
*Markle, John,	Jeddo, Luzerne Co., Pa.	'79
*Marsh, Charles W.,	126 Liberty Street, New York City.	'87
*Marsh, Walter,	Mysore W. Gold Co., Ltd., Oorgaum, Mysore, So. India.	'88
**Martin, E. P.,	Dowlais, Glamorgan, Wales.	'81
*Martin, J. B.,	Steelton, Dauphin Co., Pa.	'86
*Martin, J. F.,	Phœnix Foundry, Gawler, So. Australia.	'93
*Martin, R. L.,	8 Wood Building, Pittsburgh, Pa.	'81
*Martine, Charles A.,	Georgetown, Colorado.	'79
*Marvin, Selden E.,	Albany, N. Y.	'78
*Mason, F. H.,	Truro, Nova Scotia.	'94
*Mason, Prof. William P.,	Rensselaer Polytechnic Institute, Troy, N. Y.	'83
†Mason, Russell T.,	Michigan Mining School, Houghton, Mich.	'93
*Massenez, Joseph,	19 Parkstrasse, Wiesbaden, Germany	'91
*Mather, Samuel,	Western Reserve Building, Cleveland, Ohio.	'79

†MATHER, W. G., ... Cleveland, Ohio. '86
*MATHESON, W. G., ... New Glasgow, Nova Scotia. '85
**MATHEWSON, E. P., ... P. O. Box 719, Pueblo, Colo. '89
*MATTES, CHARLES C., ... 533 Quincy Avenue, Scranton, Pa. '87
*MATTES, W. F., ... P. O. Box 930, Pueblo, Colo. '81
*MATTHIESSEN, F. W., ... La Salle, Ill. '84
*MAURICE J., . . . Villanuevaminas, Province of Seville, Spain. '90
*MAURY, M. H., ... Max Meadows, Va. '91
*MAXON, JOHN H., . . . 2908 Washington Avenue, St. Louis, Mo. '74
*MAXWELL, J. R., ... 75 East Front Street, Cincinnati, Ohio. '84
*MAY, DE COURCY, Care Niagara Falls Power Co., Niagara Falls, N. Y. '79
*MAYNARD, GEORGE W., . 31 Nassau Street, Room 33, New York City. '71
*MAYO, JAMES H., ... 31 Nassau Street, New York City. '82
*MEAD, CHARLES W., ... Pony, Mont. '90
*MEAD, DANIEL W., ... Rockford Cons. Co., Rockford, Ill. '92
†MEANS, ARCHIBALD, ... Peru, La Salle Co., Ill. '82
*MEANS, ELLISON C., ... Ashland, Boyd Co., Ky. '88
*MEEKER, DAVID M., ... 95 Clay Street, Newark, N. J. '91
†MEEKER, STEPHEN J., ... 95 Clay Street, Newark, N. J. '91
*MEIER, EDWARD D., . . Bank of Commerce Building, St. Louis, Mo. '86
*MEIER, JOHN W., . Leopoldstrasse 42II, Karlsruhe, Baden, Germany. '74
*MEIGS, H. V. L., ... { Penn Mutual Building, 925 Chestnut Street, Philadelphia, Pa. '86
*MEISSNER, CARL A., ... P. O. Box 867, Birmingham, Ala. '87
*MEISTER, HERMAN C., ... 2008 Rutgers Street, St. Louis, Mo. '77
*MEMMINGER, C. G., ... P. O. Box 409, Bartow, Fla. '62
*MENDENHALL, THOMAS C., U. S. Coast and Geodetic Sur., Washington, D. C. '92
*MERCER, WM. A., ... Durango, Colo. '92
*MERRELL, JOSIAH M., . . . 534 Twenty-fifth Street, Oakland, Cal. '87
*MERRICKS, FRANK, 2 City Road, 14a Finsbury Sq., London E. C., England. '92
*MERRILL, CHARLES W., ... { cor. Chestnut St. and Santa Clara Ave., Alameda, Cal. '92
*MERRILL, F. J. H., . . . New York State Museum, Albany, N. Y. '85
*MERRITT, WILLIAM HAMILTON, . . 15 Toronto Street, Toronto, Canada. '79
*MERRY, HENRY G., ... Low Moor, Alleghany Co., Va. '89
†MERRYWEATHER, GEORGE, ... 601 Rookery, Chicago, Ill. '80
*METCALF, ALFRED T., ... { Swarziland by Darkton, Komati, Transvaal, So. Africa, via. Natal. '91
*METCALF, O., . . 7th Avenue and Liberty Street, Pittsburgh, Pa. '79
*METCALF, WILLIAM, ... Pittsburgh, Pa. '75
*MEYER, A. R., ... 231 Exchange Building, Kansas City, Mo. '89
*MEZGER, ADOLPH, ... P. O. Box 147, Charlotte, N. C. '91
*MICKLEY, EDWIN, ... Mickleys, Pa. '74
*MICKLEY, JOHN J., ... Mickleys, Pa. '88
*MIDDLETON, W. B., ... 725 Cooper Block, Denver, Colo. '92
*MILES, FRED. P., ... Copake Iron Works, Columbia Co., N. Y. '77
*MILLER, AUGUSTUS A., . . 623 N. 13th Street, Philadelphia, Pa. '91
*MILLER, CHARLES H., . Care New England Copper Co., Central Falls, R. I. '92
*MILLER, CHARLES L., ... 3609 Ellis Avenue, Chicago, Ill. '93
*MILLER, CHARLES W., ... P. O. Box 401, Aspen, Colo. '84
*MILLER, GEORGE S., ... Oswego, Oregon. '85

*Miller, Henry W.,	P. O. Box 98, Johannesburg Langtaagle Estate, Transvaal, So. Africa.	'92
*Miller, Horace B.,	203 Broadway, New York City.	'81
*Miller, H. B.,	Duquesne, Pa.	'91
*Miller, Leonard B.,	39 Wade Building, Cleveland, Ohio.	'93
*Miller, T. Spencer,	96 Liberty Street, New York City.	'90
*Miller, William Penn, Jr.,	P. O. Box 553, Oakland, Cal.	'93
*Mills, Charles E.,	Curtiss, Yavapai Co., Ariz.	'90
*Mills, Frank P.,	Ishpeming, Mich.	'83
*Mills, James E.,	Quincy, Plumas Co., Cal.	'77
*Mills, Samuel D.,	510 Spadma Avenue, Toronto, Canada.	'89
*Mingage, John C. H.,	Sydney, New South Wales.	'91
*Mitchell, Robert,	297 Bullitt Building, Philadelphia, Pa.	'86
*Mitchell, Walter K.,	Care Best, Fox & Co., 25th and R.R. Streets, Pittsburgh, Pa.	'92
*Mitting, E. Kennard,	423 Superior Street, Chicago, Ill.	'91
*Moen, Philip W.,	Worcester, Mass.	'82
*Moffat, A. D.,	Park City, Utah.	'88
*Mohr, Louis,	32 Illinois Street, Chicago, Ill.	'88
*Moister, Isaac R.,	Wilkes-Barre, Pa.	'91
*Molson, Charles A.,	Elkhorn, Mont.	'87
*Molson, John H. R.,	McGill University, Montreal, Canada.	'89
*Monell, Joseph T.,	Mine La Motte, Mo.	'81
*Montague, Thomas,	Hammondville, Essex Co., N. Y.	'92
*Montgomery, J. A.,	Birmingham, Ala.	'91
*Moore, Charles J.,	P. O. Box 627, Leadville, Colo.	'82
*Moore, James,	Sixteenth and Buttonwood Streets, Philadelphia, Pa.	'75
*Moore, Lycurgus B.,	203 Broadway, New York City.	'81
*Moore, Marshall G.,	244 Morris Street, Johnstown, Pa.	'86
*Moore, Philip N.,	Room 121, Laclede Building, St. Louis, Mo.	'74
*Morcom, Elisha,	Tower, Minn.	'87
*Morgan, Charles H.,	25 Lincoln Street, Worcester, Mass.	'74
*Morgan, Joseph, Jr.	Johnstown, Pa.	'81
*Morgan, T. R.,	Alliance, Ohio.	'78
*Morison, George S.,	184 La Salle Street, Chicago, Ill.	'79
*Morris, G. C.,	134 So. 4th Street, Philadelphia, Pa.	'94
*Morris, Henry,	P. O. Box 1017, Johannesburg, Transvaal, So. Africa.	'90
*Morris, Henry G.,	926 Drexel Building, Philadelphia. Pa.	'84
††Morris, Israel W.,	228 So. Third Street, Philadelphia, Pa.	'75
**Morris, Richard J.,	558 High Street, Pottstown, Pa.	'92
*Morris, S. Fisher,	Eckman, West Va.	'74
**Morris, William H.,	400 Chestnut Street, Philadelphia, Pa.	'81
*Morrison, William W.,	721 West Markham, Little Rock, Ark.	'86
*Morse, Charles S.,	P. O. Box 305, Waterbury, Conn.	'91
*Morse, H. G.,	800 Delaware Avenue, Wilmington, Del.	'81
*Morse, Jay C.,	1027 Rookery, Chicago, Ill.	'80
*Morse, Philip S.,	Germania Lead Works, Salt Lake City, Utah.	'84
*Morse, Willard S.,	Prescott, Ariz.	'92
*Moses, Otto A.,	1037 Fifth Avenue, New York City.	'81
*Moss, Prof. Milton,	4619 Ellis Avenue, Chicago, Ill.	'82
*Moxham, Edgar C.,	Mineral Trust, 33 Wall Street, New York City.	'91

*Moynau, Frank, ... South Works, So. Chicago, Ill. '94
*Mudd, Seeley W., ... P. O. Box 564, Leadville, Colo. '83
*Munroe, Prof. Henry S., . . . Columbia College, New York City. '72
†Munroe, Robert, Jr., . 23d and Smallman Streets, Pittsburgh, Pa. '92
*Munson, George C., ... P. O. Box 2465, Denver, Col. '79
*Murray, Charles B., . Care Edgar Thomson Works, Braddock, Pa. '90
**Murray, George, ... 235 W. 23d Street, New York City. '82
*Myers, George Francis, . . . 708 Penn Avenue, Pittsburgh, Pa. '91
*Myers, George H., ... Bethlehem, Pa. '91
*Myers, H. K., . . . 3423 N. Nineteenth Street, Philadelphia, Pa. '88
*Myers, John, ... Amador City, Cal. '91

*Nason, Frank, ... 5 Union Street, New Brunswick, N. J. '91
*Nason, Prof. Henry B., . Rensselaer Polytechnic Institute, Troy, N. Y. '83
*Neale, George F., ... Crystal City, Mo. '85
*Nearing, Winfield Scott, ... Morris Run, Tioga Co., Pa. '92
*Neill, James W., ... P. O. Box 760, Salt Lake City, Utah. '79
*Neill, William L., ... Solvay Process Co., Syracuse, N. Y. '80
*Neilson, James, ... Youngstown, Ohio. '79
*Neilson, William G., . . 3711 Chestnut Street, Philadelphia, Pa. '72
*Neitzell, Karl, . . . Red Mountain Milling Co., Helena, Mont. '91
*Neustaedter, A., ... Helena, Mont. '86
*Newberry, W. E., ... Enterprise Mining Co., Aspen, Colo. '85
*Newbold, John D. C., ... Norristown, Pa. '89
†Newell, Augustus W., ... Bradford, Pa. '88
*Newell, Fred. H., . Care U. S. Geological Survey, Washington, D. C. '88
†Newton, Chauncey G., ... New Straitsville, Ohio. '91
*Nicoll, Benjamin, ... 68 Wall Street, New York City. '92
*Nichols, Norman J., ... Honda, Colombia, S. A. '93
*Nichols, Ralph, ... Sutro, Lyon Co., Nev. '93
*Nicholson, Frank, ... Phœnix, Ariz. '80
*Nickels, Arthur R., Standard Smelting and Refining Co., Durango, Colo. '92
*Nimick, W. H., ... Pittsburgh, Pa. '90
*Nitze, H. B. C., ... 1505 Edmundson Avenue, Baltimore, Md. '88
*Noble, Albert E., ... Jenifer Iron Co., Jenifer, Ala. '90
*Noble, Louis S., ... Leadville, Colo. '89
*Noble, Stephen N., ... Anniston, Ala. '90
†Norrie, A. Lanfear, . . . 377 Fifth Avenue, New York City. '90
*Norris, George L., . . . 63 E. Emerson Street, Melrose, Mass. '91
*Norris, R. Van A., ... P. O. Box 726, Wilkes-Barre, Pa. '85
*Norton, Lucien H., ... Sandy, Utah. '88
*Noyes, William, ... Shafter, Presidio Co., Texas. '84
*Nye, Harold B., . 507 Western Reserve Building, Cleveland, Ohio. '85

*Oberholser, R. L., ... West Superior, Wis. '93
*Odelstjerna, E. G., ... Filipstad, Sweden. '93
*Odling, F. J., . P. O. Box 314, G. P. O., Melbourne, Victoria, Australia. '93
*Ogleray, Earl W., ... 38 Wade Building, Cleveland, Ohio. '80
*Olcott, E. E., ... 18 Broadway, New York City. '74
*Olcott, William J., ... Duluth, Minn. '87
*Oldoerp, Adolfo, ... Mapimi, Durango, Mexico. '90

*Olhausen, J. H., . . C. R. R. of N. J. Station, Jersey City, N. J. '84
*Oliver, George S., . . Richmond Gold Mines, Hillsboro, New Mex. '93
*Oliver, Henry W., Jr., . . Oliver Iron and Steel Co., Pittsburgh, Pa. '76
†Oliver, Gen. Paul A., ... Oliver's Mills, Pa. '71
*Oothout, William, Jr., . { California Petroleum and Asphalt Co., Crooker Building, San Francisco, Cal. '90
*Opperman, J. H., ... Shawnee, Perry Co., Ohio. '80
*Ord, William D., ... Landgraff, McDowell Co., W. Va. '88
*Ordway, Prof. J. M., . . Tulane University, New Orleans, La. '73
*Ormrod, George, ... 135 Fourth Street, Allentown, Pa. '81
*Ormrod, John D., ... Emaus, Lehigh Co., Pa. '89
*Ormsbee, James J., ... Pikeville, Bledsoe Co., Tenn. '87
*Orton, Edward, Jr., ... Columbus, Ohio. '83
*Orynski, L., ... San Antonio, Texas. '89
*Osgood, F. C., ... 1327 Monadnock Building, Chicago, Ill. '87
*Osmond, F., ... 83 Boulevard des Courcelles, Paris, France. '90
*Oxnam, Thomas H., ... De Lamar, Owyhee Co., Idaho. '91
*Oxnard, B. A., ... Cypremont P. O., La. '76

*Packard, George A., ... Wakefield, Mass. '92
*Packard, R. L., ... Cosmos Club, Washington, D. C. '92
*Paddock, J. H., ... St. Johnsbury, Vt. '82
*Page, George S., ... Park, Bro. & Co., Pittsburgh, Pa. '86
*Page, Walter Taylor, . Omaha & Grant S. & R. Co., Omaha, Neb. '82
*Page, William Byrd, ... P. O. Box 2089, Denver, Colo. '77
*Page, William N., ... Ansted, W. Va. '80
†Painter, Augustus E. W., . . I. Painter & Sons Co., Pittsburgh, Pa. '73
†Painter, Park, ... 245 Ridge Avenue, Allegheny, Pa. '90
*Painter, William, . . . 500 E. Monument Street, Baltimore, Md. '93
*Palacio, M. E., . Care Senor Pedro S. Delfino, Caracas, Venezuela, S. A. '86
*Palmer, Cortlandt E., . . P. O. Box 598, Colorado Springs, Colo. '89
*Palmer, Edward Vose, . . . 329 E. Arch Street, Marquette, Mich. '92
*Palmer, Obed A., Room 57, Board of Trade Building, Salt Lake City, Utah. '87
*Pani, C. E., ... Tampico Harbor Works, Tampico, Mexico. '91
*Pardee, A., Jr., ... Wyncote, Pa. '75
*Pardee, I. P., ... Stanhope, N. J. '73
*Park, Walter E., ... 2 Wall Street, New York City, '92
*Park, William G., ... Park, Bro. & Co., Pittsburgh, Pa. '81
*Parke, William G., ... Scranton, Pa. '91
*Parker, Edward W., . U. S. Geological Survey, Washington, D. C. '90
*Parker, Richard A., ... Marquette, Mich. '82
*Parker, Russell, . . American Central Building, St. Louis, Mo. '82
*Parkes, John C., ... 135 Seminary Avenue, Chicago, Ill. '75
*Parkhurst, H. W., Ill. Central R.R., 58 Michigan Avenue, Chicago, Ill. '82
*Parkin, Charles, ... Oak View, Parnassus, Pa. '75
*Parnall, S. A., . . . Cleveland Iron Mining Co., Ishpeming, Mich. '90
*Parrott, Edward M., ... Ontario, Wayne Co., N. Y. '79
*Parsons, Charles B., . . . Bonne Terre, St. François Co., Mo. '74
*Parsons, Charles O., ... 50 State Street, Boston, Mass. '74
*Parsons, William B., . . . 22 William Street, New York City. '91
*Partington, Gerard J., . . Whiteburn Mines, Queen Co., Nova Scotia. '91

*Partridge, John A., . . . 518 Thirteenth Street, Washington, D. C. '90
*Patch, Maurice B., ... 1 Austin Street, Buffalo, N. Y. '83
*Patterson, G. S., ... Vivian, McDowell Co., W. Va. '88
*Patterson, R. P., ... Pulaski, Va. '86
*Patterson, S. B., ... Dover, N. J. '88
*Patterson, William E., ... Berkeley, Cal. '88
*Paul, Henry, ... 1724 Ogden Street, Denver, Colo. '89
*Payette, Joseph, ... Ferrona, Clinton Co., N. Y. '89
*Payne, A. C., ... Rat Portage Mining and Red. Co., Rat Portage, Ontario, Canada. '91
*Payne, C. Q., ... Stamford, Conn. '81
*Payne, Edward C., . 163 Victoria Street, Ballarat, Victoria, Australia. '93
*Payne, Prof. J. K., ... 120 Clinton Street, Knoxville, Tenn. '92
*Payne, W. G., ... Kingston, Luzerne Co., Pa. '91
*Peacock, Francis T., ... U. S. Car Co., Anniston, Ala. '88
**Pearce, Richard, ... Argo, Colo. '74
*Pearsall, H. D., 16 Willows Road, Hampstead, N. W., London, England. '82
**Pearse, Arthur L., . Care Bainbridge, Seymour & Co., 13 St. Helen's Place, London, E. C., England. '90
**Pearse, John B., ... Roxbury, Mass. '72
**Pearson, John E., ... Athenæum, Liverpool, England. '82
*Pearson, J. F., ... Broken Hill Prop. Co., Broken Hill, New South Wales. '93
*Pease, F. N., ... P. O. Box 210, Altoona, Pa. '82
*Pechin, Edmund C., . . . 587 Prospect Street, Cleveland, Ohio. '71
†Pechin, John S., . . . 220 West Chester Park, Boston, Mass. '92
*Peck, Orrin B., . . . 162 Thirty-fourth Street, Chicago, Ill. '89
*Peckitt, Leonard, ... Crane Iron Works, Catasauqua, Pa. '83
*Pedley, William E., . Care Holcomb Valley Co., Limited, Victor, Cal. '91
*Peele, R., Jr., . Columbia College, Forty-ninth Street, New York City. '83
*Pelouze, Frederick, . . . Illinois Steel Co., South Chicago, Ill. '92
*Pender, James W., ... Fort Lee, N. J. '88
*Penfield, Edward W., . . . 2456 Prairie Avenue, Chicago, Ill. '86
*Penhale, Matthew, . . Black Lake, Megantic Co., P. Q., Canada. '91
*Pennie, J. C., ... 608 F Street, N. W., Washington, D. C. '92
*Pennock, J. D., ... Solvay Process Co., Syracuse, N. Y. '89
*Penrose, R. A. F., Jr., . . 1331 Spruce Street, Philadelphia, Pa. '89
*Perin, Charles Page, ... Pikeville, Bledsoe Co., Tenn. '90
**Perkins, H. C., . 5 Union Court, Old Broad St., London, E. C., England. '81
*Perkins, Thomas Slade, ... 39 Garden Place, Brooklyn, N. Y. '93
*Perry, W. A., ... 86 Liberty Street, New York City. '83
*Peters, E. D., Jr., Care Dr. Cushing, Percival Avenue, Dorchester, Mass. '85
**Peters, J. C., ... Helena, Mont. '89
*Peters, Richard, Jr., . . 220 S. Fourth Street, Philadelphia, Pa. '84
*Peters, Samuel, . . . 22 Bramhall Street, Portland, Maine. '83
**Pettee, Prof. William H., University of Michigan, Ann Arbor, Mich. '71
*Pettigrew, Charles, . . . Care Illinois Steel Co., Joliet, Ill. '84
*Pfordte, Otto F., . . 40 Sherman Place, Jersey City Heights, N. J. '89
*Phillips, A. G., . . Oriental and Sheba Valley, U. S. Mining Co., Eureka City, Barberton, Transvaal, So. Africa. '91
*Phillips, Thomas H., ... St. Davids, Delaware Co., Pa. '87

*Phillips, William B.,	Birmingham, Ala.	'87
*Phipps, Henry, Jr.,	48 Fifth Avenue, Pittsburgh, Pa.	'88
*Pickford, Walter W.,	Boyd, Marion Co., Fla.	'93
*Pierce, Frank M.,	42 Cortlandt Street, New York City.	'83
*Pierce, James B.,	Sharpsville, Pa.	'86
*Pierce, Josiah, Jr.,	11 South Street, Baltimore, Md.	'90
†Pilling, William S.,	Bullitt Building, Philadelphia, Pa.	'91
*Pinder, Joseph W.,	Supt. Cachivi Co., Tumaco, Ecuador, S. A.	'92
*Pinkham, W. F.,	Mount Vernon, N. H.	'82
*Pistor, William,	1 Madison Avenue, New York City.	'88
*Pitcairn, Robert,	Pittsburgh, Pa.	'81
*Pitkin, S. H.,	104 Park Street, Akron, Ohio.	'87
*Pitman, Prof. S. M.,	Germantown, Philadelphia, Pa.	'73
**Plater, John E.,	Los Angeles, Cal.	'73
*Platt, F. E.,	Scranton, Pa.	'81
*Platt, Franklin,	1319 Walnut Street, Philadelphia, Pa.	'72
**Platt, Joseph C.,	P. O. Box 575, Waterford, N. Y.	'73
**Pluemer, A.,	Room 3, Chamber of Commerce Building, Cincinnati, Ohio.	'81
*Plumb, Robert E.,	1 Newberry & McMillan Building, Detroit, Mich.	'84
*Plummer, John W.,	Montana National Bank, Helena, Mont.	'80
*Poage, J. G.,	B. H. Cent. S. M. Co., Broken Hill, New South Wales.	'92
†Polk, Rufus K.,	Danville, Pa.	'87
*Polledo, Y.,	Apartado 167, Matanzas, Cuba.	'89
*Pollok, James H.,	37 Athole Gardens, Glasgow, Scotland.	'93
**Pomeroy, James H.,	Oswego, Oregon.	'89
*Pomeroy, Richard A.,	New Iberia, La.	'82
*Poole, Henry S.,	Stellarton, Nova Scotia.	'85
*Pope, George A.,	Keyser Building, Baltimore, Md.	'92
*Pope, J. D.,	Winston, Mont.	'91
*Pope, Thomas E.,	Mass. Institute of Technology, Boston, Mass.	'86
*Porter, H. H., Jr.,	42 E. Forty-first Street, New York City.	'86
*Porter, H. K.,	Pittsburgh, Pa.	'86
*Porter, J. A.,	804 Boston Building, Denver, Colorado.	'74
*Porter, J. C.,	Spang Steel and Iron Co., Pittsburgh, Pa.	'82
*Porter, J. M.,	Lafayette College, Easton, Pa.	'91
*Porter, John B.,	C. H. and D. R. R. Co., Cincinnati, Ohio.	'83
Pošepný, Bergrath Franz,	XIX Karl Ludwigstrasse 62, Vienna, Austria.	
*Potter, Edward C.,	1161 Rookery, Chicago, Ill.	'79
*Potter, J. A.,	Cleveland Steel Co., Cleveland, Ohio.	'90
*Potter, O. W.,	1027 Rookery, Chicago, Ill.	'75
*Potter, Prof. William B.,	1225 Spruce Street, St. Louis, Mo.	'71
*Potts, George E.,	Eagle Mines, Fla.	'88
*Potts, George H.,	Pottstown, Pa.	'88
*Potts, F. L.,	3903 Spruce Street, Philadelphia, Pa.	'82
*Potts, Henry,	419 Walnut Street, Philadelphia, Pa.	'92
*Potts, William M.,	Wyebrook, Chester Co., Pa.	'86
*Powel, De Veaux,	29 Broadway, New York City.	'84
*Powell, J. W.,	P. O. Box 585, Washington, D. C.	'76
*Power, Frederick D.,	10 Blessington Road, Lee, Kent, England.	'91
*Power, I. M.,	Consulado Britanico, Linares, Provincia de Jaen, Spain.	'88
*Pratt, Nathaniel W.,	30 Cortlandt Street, New York City.	'86

*Prentiss, F. H.,	753 Monadnock Building, Chicago, Ill.	'88
*Prebbrey, Oliver S.,	Port Henry, Essex Co., N. Y.	'78
*Prevost, S. M.,	233 S. Fourth Street, Philadelphia, Pa.	'81
*Price, Thomas,	524 Sacramento Street, San Francisco, Cal.	'85
*Pritchett, C. W.,	Apartado 84, Pachuca, Mexico.	'86
*Proust, Réné,	Shamrock Lead G. Mining Co., Addison's Flat, Westport, New Zealand.	'91
*Provis, John,	Burnie, Emu Bay, Tasmania, Australia.	'78
*Provis, Richard,	Comstock, West Coast, Tasmania.	'91
**Pullman, J. Wesley,	238 S. Third Street, Philadelphia, Pa.	'81
*Pullon, J. T.,	Pachuca, Mexico.	'91
†Purbeck, George A.,	114 5th Avenue, New York City.	'92
*Purnell, F. H.,	Snow Hill, Md.	'86
†Quier, Edwin A.,	Care McHose & Co., Reading, Pa.	'92
†Quier, Levi,	Reading, Pa.	'90
*Quintard, Edward A.,	Sewanee, Tenn.	'89
*Rader, Charles I.,	Paxton Furnace, Harrisburg, Pa.	'75
†Radford, W. H.,	Weaverville, Trinity Co., Cal.	'76
*Raht, A.,	Care Phila. S. & R. Co., Pueblo, Colo.	'86
*Ralston, W. C.,	Mills Building, San Francisco, Cal.	'90
*Ramsay, Erskine,	Pratt Mines, Ala.	'88
*Ramsay, G. S.,	Coketon, Tucker Co., W. Va.	'89
*Rand, Addison C.,	23 Park Place, New York City.	'76
*Rand, Jasper R.,	23 Park Place, New York City.	'82
†Rand, Theodore D.,	17 S. Third Street, Philadelphia, Pa.	'73
*Randol, James B.,	P. O. Box 2548, San Francisco, Cal.	'79
*Randolph, Beverley S.,	Frostburg, Md.	'91
*Randolph, John C. F.,	35 Wall Street, New York City.	'75
*Rathbone, Edgar P.,	Care Bewick, Moreing & Alford, Johannesburg, Transvaal, So. Africa.	'82
*Rattle, W. J.,	58 Grand Arcade Building, Cleveland, Ohio.	'84
†Raunheim, S. E.,	50 E. Seventy-ninth Street, New York City.	'87
*Ravenscroft, W. S.,	Shawmut Clay Manufacturing Co., Ridgway, Pa.	'92
*Rawlings, Charles Q.,	739 Main Street, Wheeling, W. Va.	'91
*Ray, Frank A.,	Congo, Perry Co., Ohio.	'90
*Raymond, R. M.,	Care Diamond Rock M. Co., Neihart, Mont.	'85
**Raymond, R. W.,	P. O. Box 223 (13 Burling Slip), New York City.	'71
†Rea, Wm. H.,	Robinson Rea Manufacturing Co., Pittsburgh, Pa.	'86
†Reddy, P.,	330 Pine Street, San Francisco, Cal.	'92
*Reed, S. Albert,	Union Club, Chicago, Ill.	'75
*Reets, H. S.,	P. O. Box 1092, Wilkes-Barre, Pa.	'87
*Reese, Arnold K.,	1801 Linden Avenue, Baltimore, Md.	'91
*Reese, Edward,	Centralia, Columbia Co., Pa.	'93
*Reeves, David,	Phœnix Iron Co., Philadelphia, Pa.	'86
*Reid, John H.,	"Stannum," Tenderfield, New South Wales.	'91
*Reid, John M.,	Oxford Gold Mines, Musquodoboit Harbor, Nova Scotia.	'89
*Reilly, A. J.,	Pratt Mines, Ala.	'91
*Reinhardt, H. O.,	Apartado 36, Chihuahua, Mexico.	'83
*Reno, Jesse W.,	Care Rapid Trans. & B. Con. Co., Mills Building, New York City.	'87

*Revere, Joseph W.,	Caledonia Mines, Cape Breton, Nova Scotia.	'81
*Reyburn, Amedee V.,	3737 Lindell Avenue, St. Louis, Mo.	'94
**Reynolds, George B.,	Grindlay, Groom & Co., Bombay, India.	'91
*Rhodes, F. B. F.,	National Smelting and Ref. Co., So. Chicago, Ill.	'76
*Rhodes, R. D.,	Ark. Valley Smelting Works, Leadville, Colo.	'86
*Rice, George S.,	95 Milk Street, Boston, Mass.	'86
*Rice, John,	560 High Street, Pottstown, Pa.	'92
*Rich, Frank A.,	Room 5, Sheridan Building, Denver, Colo.	'94
†Rich, Jacob M.,	50 W. Thirty-eighth Street, New York City.	'83
*Rich, William,	Minas de Rio Tinto, Provincia de Huelva, Spain.	'88
**Richards, Edgar,	1621 H Street, Washington, D. C.	'79
*Richards, Ellen H.,	Mass. Institute of Technology, Boston, Mass.	'79
*Richards, E. Windsor,	Low Moor Iron Works, Bradford, Yorkshire, England.	'81
*Richards, F. B.,	Buena Vista Iron Co., Buena Vista, Va.	'90
*Richards, George,	Dover, N. J.	'75
**Richards, Henry,	Dover, N. J.	'77
**Richards, John Thompson,	Scorries, Cornwall, England.	'84
*Richards, John W.,	P. O. Box 247, Aspen, Colo.	'91
*Richards, W. J.,	Wilkes-Barre, Pa.	'90
*Richards, Prof. R. H.,	Mass. Institute of Technology, Boston, Mass.	'73
*Richards, Thomas,	6 Endsleigh Terrace, Tavistock, England.	'92
*Riché, M. G.,	Ocala, Fla.	'94
*Richmond, William H.,	Scranton, Pa.	'87
Richter, Prof. Theodor,	Freiberg, Saxony, Germany.	
*Rickard, Alfred,	207 McPhee Building, Denver, Colo.	'84
*Rickard Forbes,	Central City, Colo.	'92
*Rickard, Reuben,	Berkeley, Cal.	'84
*Rickard, R. D.,	56 Beaver Street, New York City.	'80
*Rickard, Thomas,	35 Queen Victoria Street, London, England.	'85
*Rickard, Thomas, Jr.,	21 Fremont Street, San Francisco, Cal.	'89
*Rickard, T. A.	207 McPhee Building, Denver, Colo.	'88
†Ricketson, J. H.,	10 Wood Street, Pittsburgh, Pa.	'72
*Ricketts, L. D.,	Rawlins, Wyoming.	'92
*Ricketts, Dr. P. De P.,	104 John Street, New York City.	'73
*Ridgely, Charles,	Springfield Iron Co., Springfield, Ill.	'75
*Ridgely, William B.,	Springfield Iron Co., Springfield, Ill.	'80
*Riddle, James,	P. O. Box 85, Norfolk, Va.	'94
*Riebel, Otto F.,	112 Chamber of Commerce, Duluth, Minn.	'92
*Riggs, George W.,	Summit, N. J.	'74
*Riley, James,	23 Royal Exchange Square, Glasgow, Scotland.	'82
*Riley, Lewis A.,	222 Walnut Street, Philadelphia, Pa.	'76
*Riley, S. M.,	Ashland, Schuylkill Co., Pa.	'82
*Riordan, D. M.,	Flagstaff, Ariz.	'82
*Risque, J. B.,	Old Abe Mine, White Oaks, New Mex.	'83
*Rissmann, Otto,	1225 Spruce Street, St. Louis, Mo.	'89
*Robbins, S. B.,	Great Falls, Mont.	'91
†Roberts, E. C.,	18 White Building, Buffalo, N. Y.	'88
*Roberts, F. C.,	S. E. Cor. Fourth and Chestnut Streets, Philadelphia, Pa.	'87
*Roberts, George M.,	Assay Office, B. H. Proprietary Co., Ltd., Broken Hill, New South Wales.	'92

*ROBERTS, PERCIVAL, . . . 261 S. Fourth Street, Philadelphia, Pa. '81
*ROBERTS, PERCIVAL, JR., . . 261 S. Fourth Street, Philadelphia, Pa. '77
*ROBERTSON, DAVID, ... Ridgway, Pa. '85
†ROBERTSON, JAMES D., Roe Building, Fifth and Pine Streets, St. Louis, Mo. '86
*ROBERTSON, KENNETH, Care West Superior I. and S. Co., West Superior, Wis. '82
*ROBERTSON, NATHANIEL G., . Maryland Steel Co., Sparrow's Point, Md. '89
*ROBERTSON, W. F., ... 77 Pine Street, New York City. '81
*ROBESON, A. M., . De Beers Consolidated Mines, Kimberly, So. Africa. '93
*ROBESON, J. S., . . Care Carnegie, Phipps & Co., Ltd., Braddock, Pa. '85
*ROBINS, THOMAS, JR., ... 64 Cortlandt Street, New York City. '92
*ROBINSON, C. SNELLING, . Care Colo. Fuel and Iron Co., Pueblo, Colo. '85
*ROBINSON, DAVID S., ... Ford City, Armstrong Co., Pa. '85
*ROBINSON, GEORGE H., . . Mammoth Mining Co., Mammoth, Utah. '86
*ROBINSON, SANFORD, . . 320 Sansome Street, San Francisco, Cal. '90
*ROBINSON, THEODORE W., . . Colo. Fuel and Iron Co., Pueblo, Colo. '84
*ROBY, LUTHER A., . . . 745 Genesee Avenue, Cleveland, Ohio. '79
*ROCKWELL, GEORGE J., ... P. O. Box 13, Argentine, Kan. '87
*RODERICK, JAMES E., . . . 419 Cranberry Avenue, Hazleton, Pa. '91
*ROE, JAMES P., ... 721 King Street, Pottstown, Pa. '91
*ROEPPER, C. W., ... Alliance, Ohio. '73
*ROGERS, ALLEN H., ... Copper Basin, via Prescott, Ariz. '92
*ROGERS, E. M., ... P. O. Box 716, Denver, Colo. '82
*ROLKER, CHARLES M., ... 18 Broadway, New York City. '74
*ROLLINS, EDWARD W., ... P. O. Box 984, Denver, Colo. '89
*ROOSEVELT, ELLIOTT, ... { Knickerbocker Club, 319 5th Avenue, New York City. '93
†ROSE, WILLIAM J., ... 413 Market Street, Harrisburg, Pa. '81
*ROSE, WILLIAM W., ... P. O. Box 155, El Paso, Texas. '82
*ROSECRANS, GEN. W. S., . . Treasury Department, Washington, D. C. '76
*ROSELL, C. A. O., . . . 1131 Ninth Street, Washington, D. C. '91
*ROSEWARNE, D. D., ... Blinman, So. Australia. '90
*ROSS, FRANK A., ... P. O. Box 315, Seattle, Wash. '85
*ROSSI, AUGUSTE J., . . . 35 Broadway, Room 100, New York City. '92
*ROTHWELL, JOHN E., ... Sumpter, Oregon. '88
*ROTHWELL, R. P., ... P. O. Box 1833, New York City. '71
*ROWE, DANIEL, . . Trevingey Terrace, Redruth, Cornwall, England. '92
*RUETSCHI, RUDOLF, ... Argentine, Kansas. '91
†RUNYON, WALTER C., . . 506 Perry Payne Building, Cleveland, Ohio. '92
*RUSSELL, A. J. . . . . { Care Señor Don José M. Restrepo, Honda, Columbia, S. A. '92
*RUSSELL, EDWARD H., ... Park City, Utah. '84
*RUSSEL, W. S., ... 863 Jefferson Avenue, Detroit, Mich. '86
*RUTTMANN, FERD. S., . . . 35 Broadway, Room 47, New York City. '81
*RYON, A. M., ... Bozeman, Mont. '89

*SADDLER, VALENTINE J., . . { 422 Flinders Lane, W., Melbourne, Victoria, Australia. '93
*SAHLIN, AXEL, . . . Maryland Steel Co., Sparrow's Point, Md. '91
*SALOM, PEDRO G., . . . 926 Drexel Building, Philadelphia, Pa. '80
*SALSBURY, M. K., ... Calumet Coke Co., Pittsburgh, Pa. '90
†SANBORN, EDWARD H, . . Manufacturer's Record, Baltimore, Md. '91

**SANDBERG, C. P., 19 Great George St., Westminster, London, S. W., England. '81
*SANDERS, JOHN D., ... Mine La Motte, Mo. '79
*SANDERS, R. H., . . Room 401, Drexel Building, Philadelphia, Pa. '76
*SANDERS, W. E., ... P. O. Box F, Helena, Mont. '85
*SANDS, WILLIAM B., ... P. O. Box 93, Sparrow's Point, Md. '93
*SAN ROMAN, FRANCISCO I., . . . { Egercito Libertado 63, Santiago de Chile, Chile, S. A. '92
†SARGEANT, F. E., ... Butte, Mont. '87
*SAUNDERS, WILLIAM E., ... Negaunee, Mich. '89
*SAUVEUR, ALBERT, . . Care Illinois Steel Co., South Chicago, Ill. '92
*SAVAGE, ARTHUR E., ... Broken Hill, New South Wales. '91
*SAWYER, EDWARD T., . . . Care Columbus Club, Columbus, Ohio. '94
*SAWYER, WILLARD N., . . . 26 Stearns Street, Cleveland, Ohio. '93
*SAYLOR, LIVINGSTON, . Philadelphia Bridge Works, Pottstown, Pa. '92
*SAYR, HAL., ... 8 Craigie Street, Cambridge, Mass. '89
†SCAIFE, CHARLES C., ... 119 First Avenue, Pittsburgh, Pa. '86
*SCAIFE, MARVIN F., ... Morganton, N. C. '90
**SCAIFE, OLIVER P., ... 119 First Avenue, Pittsburgh, Pa. '78
**SCAIFE, WILLIAM LUCIEN, Scaife Foundry & Machine Co., Pittsburgh, Pa. '79
*SCALLON, WILLIAM, ... Butte, Mont. '90
††SCHAEFFER, DR. CHARLES, . 1309 Arch Street, Philadelphia, Pa. '92
*SCHAEFFER, CHARLES F., . Care McConway & Torley Co., Pittsburgh, Pa. '92
*SCHARAR, C. H., ... 2073 N. Main Avenue, Scranton, Pa. '82
*SCHEIDEL, DR. A., ... Care Post Office, Cooke, Mont. '93
*SCHELLENBERG, F. Z., . . . 159 First Avenue, Pittsburgh, Pa. '79
*SCHLEMM, WILLIAM H., ... Durango, Mexico. '82
†SCHLESINGER, FERDINAND, . New Insurance Building, Milwaukee, Wis. '90
*SCHMIDT, HENRY A., ... Chloride, New Mex. '87
*SCHMITERLOW, C. G. E., . . . P. O. Box 841, Worcester, Mass. '90
*SCHMITZ, E. J., ... 164 E. 80th Street, New York City. '83
*SCHNEIDER, ALBERT F., ... Monterey, Mexico. '74
*SCHNEIDER, PAUL, . . . 32 rue de la Ville l'Evêque, Paris, France. '93
*SCHOLL, GEORGE, ... Crane Iron Works, Catasauqua, Pa. '92
†SCHOONMAKER, S. L., Care Fricke Coke Co., 46 Wall Street, New York City. '86
*SCHROEDTER, E., . . . Schadowplatz 14, Düsseldorf, Germany. '91
†SCHROPP, A. S., ... Bethlehem Iron Co., Bethlehem, Pa. '86
*SCHULZE-BERGE, H., ... 156 Clinton Street, Brooklyn, N. Y. '81
*SCHUMACHER, A. J., ... Argenta, Beaver Head Co., Mont. '89
*SCHWAB, CHARLES M., ... Braddock, Pa. '91
†SCHWARTZ, J. E., ... P. O. Box 1062, Pittsburgh, Pa. '76
*SCHWARZ, T. E., ... 4 Bank Block, Denver, Colorado. '76
*SCOTT, FREDERICK BOWES, . 13 St. Helen's Place, London, E. C., England. '91
*SCOTT, JAMES, ... Lucy Furnace, Pittsburgh, Pa. '90
*SCOTT, JOHN HOAG, . . Cornwall Anthracite Furnaces, Cornwall, Pa. '92
*SCOTT, ROBERT J., . . . Negley Avenue, E. E., Pittsburgh, Pa. '90
*SCRANTON, W. W., ... Scranton, Pa. '75
**SEAMAN, HENRY B., Eng. Const., N. Y., N. H. & H. R.R., Mt. Vernon, N. Y '89
*SEAMAN, H. J., ... Catasauqua, Pa. '82
*SEAMON, W. H., ... Rollo, Mo. '90
†SEARLE, J. M., ... Grand Rivers, Ky. '84
*SEARS, EDWARD H., ... Collinsville, Conn. '81

*SEBENIUS, J. UNO, . . 631 Chamber of Commerce, Duluth, Minn. '90
*SECCOMBE, ALFRED F., . . Albaston, Gunnislake, Cornwall, England. '92
*SEDDON, RICHARD JOHN, . Ministers Office, Wellington, New Zealand. '88
*SEDDON, THOMAS, ... Birmingham, Ala. '88
*SEE, HORACE, ... 1 Broadway, New York City. '90
**SELIGMAN, A. J., ... Helena, Mont. '82
*SELLERS, MORRIS, ... 216 Phœnix Building, Chicago, Ill. '84
*SELLERS, WILLIAM, . . . 1600 Hamilton Street, Philadelphia, Pa. '75
Serlo, Bergrath Albert, ... Berlin, Germany.
*SETTERWALL, H. A. F., . . Mutual Life Ins. Co., Stockholm, Sweden. '88
*SETZ, GUSTAV, St. Joseph Lead Mines, Bonne Terre, St. François Co., Mo. '77
*SEYMOUR, L. I., . . 43 Threadneedle Street, London, E.C., England. '93
*SHARP, CHARLES C., ... Corning, Ohio. '94
*SHARP, WILLIAM G., ... Castle Gate, Emery Co., Utah. '91
*SHARPLESS, FRED F., ... Houghton, Lake Superior, Mich. '89
*SHARPLES, S. P., ... 13 Broad Street, Boston, Mass. '78
*SHEAFER, A. W., ... Pottsville, Pa. '80
*SHEAFER, S. TAYLOR, ... New Bethlehem, Pa. '85
*SHEAFER, W. LESLEY, ... Pottsville, Pa. '81
*SHED, NATHANIEL W., ... Burden, N. Y. '82
*SHENNAN, JOHN, . . . Great Falls Iron Works, Great Falls, Mont. '90
*SHEPHARD, R., . Broken Hill Prop. Co., Broken Hill, New South Wales. '93
*SHERRERD, ALEXANDER H., Lackawanna Iron and Coal Co., Scranton, Pa. '75
*SHERRERD, JOHN M., . . . Troy Steel and Iron Co., Troy, N. Y. '80
*SHERRERD, MORRIS R., ... 116 First Street, Troy, N. Y. '89
**SHIELDS, CHARLES O., . Room 725, Cooper Building, Denver, Colo. '88
*SHIMER, PORTER W., ... Easton, Pa. '79
*SHOCKLEY, W. H., . . . Bohemian Club, San Francisco, Cal. '83
*SHOOK, A. M., ... Tracy City, Tenn. '85
†SIDERFIN, WILLIAM C., . . . P. O. Box 1313, Walkerville, Mont. '91
*SILLIMAN, PROF. J. M., . . . Lafayette College, Easton, Pa. '71
*SIMMONS, A. J., ... Keystone, Etta Mine P. O., So. Dakota. '89
*SIMONDS, FRANCIS M., . . 227 Sandford Avenue, Flushing, N. Y. '88
*SIMPSON, C. D., ... Scranton, Pa. '85
*SIMPSON, J. C., ... Laclede Building, St. Louis, Mo. '87
*SIMPSON, H. P., ... P. O. Box 485, Scranton, Pa. '91
*SIMS, ALFRED W., . . . Rockhill Furnace, Huntingdon Co., Pa. '85
*SIMS, H. N., ... Shenandoah, Va. '83
*SINGER, GEORGE, ... 111 Fourth Avenue, Pittsburgh, Pa. '85
*SINGER, WILLIAM H., . . . Singer, Nimick & Co., Pittsburgh, Pa. '73
*SINGER, R. R., ... 111 Fourth Avenue, Pittsburgh, Pa. '79
**SJÖGREN, HJALMAR, ... Upsala, Sweden. '91
*SJÖSTEDT, ERNST A., . Pictou Charcoal Iron Co., Bridgeville, Nova Scotia. '93
*SKELDING, JOSEPH F., ... Ensley, Ala. '91
*SKIFF, F. J. V., ... 5014 Jefferson Avenue, Chicago, Ill. '93
*SKINNER, T. L., ... Terraville, So. Dakota. '88
*SLINGLUFF, WILLIAM F., ... Norristown, Pa. '87
*SLOSS, FRED., ... Birmingham, Ala. '86
*SLUDER, EDWIN E., ... Cerrillos, Santa Fe Co., New Mex. '83
**SMALL, GEORGE W., ... Visalia, Cal. '85
*SMALL, HENRY BEAUMONT, Department of Agriculture, Ottawa, Canada. '89

†SMINK, FRANK C., ... Reading Iron Co., Reading, Pa. '92
*SMITH, A. D. W., . Room 18, 4th Floor, Post Office, Philadelphia, Pa. '87
†SMITH, A. P., ... 261 Broadway, New York City. '90
*SMITH, BOYD, ... 1836 Jefferson Place, Washington, D. C. '89
†SMITH, CLEMENT GRUBB, ... Joanna Furnace, Pa. '92
*SMITH, EDGAR F., . . University of Pennsylvania, Philadelphia, Pa. '93
*SMITH, FRANK C., ... Richland Center, Wis. '84
*SMITH, FRANK MARSHALL, United Smelting and Ref. Co., Smelter, Mont. '92
*SMITH, FREDERICK H., . . 227 E. German Street, Baltimore, Md. '90
*SMITH, GEORGE, . Aust., B. H. Consols, Broken Hill, New South Wales. '92
*SMITH, HAMILTON, JR., . . 30 St. Swithin's Lane, London, England. '77
*SMITH, H. E., . . . 133 Twenty-Sixth Street, Milwaukee, Wis. '91
*SMITH, H. S., ... 4727 Greenwood Avenue, Chicago, Ill. '75
*SMITH, J. BENNETT, ... Kingston, Pa. '91
*SMITH, J. D. AUDLEY, . . . Arizona Copper Co., Clifton, Ariz. '93
*SMITH, J. WILLIAM, ... Solvay Process Co., Syracuse, N. Y. '81
*SMITH, M. E., ... U. S. Mint, Denver, Colo. '89
*SMITH, MICHAEL, . . . 9136 Exchange Avenue, S. Chicago, Ill. '84
*SMITH, NOAH B., . . Sloss Iron and Steel Co., Birmingham, Ala. '86
*SMITH, OBERLIN, ... Ferracute Machine Co., Bridgeton, N. J. '84
†SMITH, PEMBERTON, . . German Insurance Building, Buffalo, N. Y. '94
*SMITH, T. GUILFORD, ... P. O. Box 156, Buffalo, N. Y. '71
*SMITH, WILLIAM ALLEN, . . . 52 Wall Street, New York City. '73
*SMITH, GEN. WILLIAM SOOY, . . 100 Washington Street, Chicago, Ill. '76
*SMITH, W. T., ... P. O. Box 446, Scranton, Pa. '87
**SMOCK, PROF. JOHN C., . Geological Survey of N. J., Trenton, N. J. '73
*SMYTH, C. H., ... Franklin Iron Works, Oneida Co., N. Y. '82
*SMYTH, C. H., Jr., ... Clinton, N. Y. '87
*SMYTH, HENRY LLOYD, . . . 16 Oxford Street, Cambridge, Mass. '90
*SNOW, CHARLES HENRY, . . . { University Building, Washington Square, New York City. '91
*SNOW, G. W., . . . Room 2, 49 Main Street, Salt Lake City, Utah. '91
*SNYDER, J. F., ... 1015 Vine Street, Scranton, Pa. '76
*SOHON, MICHAEL D., ... South Bethlehem, Pa. '91
**SONNEMANN, GEORGE A., . . . { Bunker Hill & Sullivan Manufacturing Co., Kellogg, Idaho. '91
*SORGE, KURT, ... Esplanadenstrasse 16, Metz, Germany. '86
*SOTTER, J. C., ... 175 N. Hanover Street, Pottstown, Pa. '92
*SOULE, R. H., ... N. and W. R.R., Roanoke, Va. '81
*SOUTHER, JOHN I., ... Illinois Steel Co., S. Chicago, Ill. '89
*SPEER, JOHN Z., ... Shoenberger & Co., Pittsburgh, Pa. '79
*SPENCER, EUGENE J., . . . 513 Security Building, St. Louis, Mo. '91
**SPERR, FRED W., . . 1461 Worthington Street, Columbus, Ohio. '82
*SPERRY, EDWIN A., ... Dubois, Colo. '89
*SPERRY, FRANCIS L., ... Talmadge, Ohio. '89
*SPERRY, JAMES A., ... Sunset, Colo. '90
*SPIES, ALBERT, ... 901 Summit Avenue, Jersey City, N. J. '81
*SPILSBURY, E. G., . . . Trenton Iron Works, Trenton, N. J. '73
*SPOTSWOOD, GEORGE A., ... Kingston, Ontario, Canada. '89
*SPROW, JOHN H., . . . Wellman Iron and Steel Co., Thurlow, Pa. '93
†SQUIER, CHARLES B., ... 111 Liberty Street, New York City. '86

*Squire, F. B.,	Standard Block, Cleveland, Ohio.	'93
**Squire, Joseph,	Helena, Shelby Co., Ala.	'71
*Stafford, C. Edward,	Care Shoenberger & Co., Pittsburgh, Pa.	'74
*Stanford, H. R.,	Care Pratt and Letchworth, Buffalo, N. Y.	'94
*Stanley, Henry M.,	921 So. Logan Street, Cleveland, Ohio.	'89
**Stanton, Frank McM.,	Atlantic Mine P. O., Houghton Co., Mich.	'89
†Stanton, John,	76 Wall Street, New York City.	'77
*Stanton, Robert B.,	50 Broadway, New York City, and Los Angeles, Cal.	'92
*Starek Emil,	303 Times Building, St. Louis, Mo.	'92
*Starr, James,	Landon Iron Co., Chapinville, Conn.	'93
*Stauffer, D. McNeely,	Tribune Building, New York City.	'91
**Staunton, William F.,	Tombstone, Ariz.	'83
*Stearns, George H.,	70 Kilby Street, Boston, Mass.	'88
*Stearns, I. A.,	Wilkes-Barre, Pa.	'71
*Stearns, Thomas B.,	Duff Block, Denver, Colo.	'89
*Steedman, James H.,	2803 Pine Street, St. Louis, Mo.	'89
*Steele, Thomas C.,	Pottstown Iron Co., Pottstown, Pa.	'90
*Stein, Walter M.,	323 Walnut Street, Philadelphia, Pa.	'88
*Stetefeldt, C. A.,	967 Alice Street, Oakland, Cal.	'81
*Stevenson, A. A.,	Standard Steel Works, Burnham, Mifflin Co., Pa.	'89
*Stevenson, John, Jr.,	New Castle, Pa.	'76
*Stevenson, Robert,	2120 Suther Street, San Francisco, Cal.	'89
*Sticht, Ernest,	412 Main Street, Butte, Mont.	'85
*Sticht, Robert,	Helena, Mont.	'85
*Stickney, Charles Wade,	P. O. Box 208, Ketchum, Idaho.	'91
*Stillman, Prof. T. B.,	Stevens Institute, Hoboken, N. J.	'85
*Stirling, W. R.,	1027 Rookery, Chicago, Ill.	'84
*Stockett, Lewis,	164 Laclede Building, St. Louis, Mo.	'81
*Stoddard, Arthur B.,	P. O. Box 521, La Salle, Ill.	'91
*Stoek, Harry H.,	State College, Pa.	'88
*Stoiber, Edward G.,	P. O. Box 129, Silverton, Colo.	'77
*Stone, George C.,	N. J. Zinc and Iron Co., Newark, N. J.	'80
*Stonestreet, George D.,	315 Dearborn Street, Chicago, Ill.	'88
*Storer, John,	P. O. Box 220, Sydney, New South Wales.	'89
*Stott, Walter E.,	Crown Point, N. Y.	'92
*Stoughton, H. R.,	74 East College Street, Oberlin, Ohio.	'89
*Strickland, Herbert,	Care Wardell & Dustan, Aspen, Colo.	'84
*Strieby, Prof. William,	Colorado College, Colorado Springs, Colo.	'77
*Striedinger, J. H.,	Room 56, Academy of Science, 819 Market Street, San Francisco, Cal.	'93
*Strobel, V. O.,	Mifflin and Meadow Streets, Philadelphia, Pa.	'84
*Struthers, Joseph, Jr.,	Columbia College, New York City.	'88
*Stuart, George W.,	Truro, Nova Scotia.	'93
*Stubbs, Frederick,	Cyclops Steel and Iron Works, Sheffield, England.	'93
*Stutz, Sebastian,	708 Penn Avenue, Pittsburgh, Pa.	'79
*Suels, Joseph K.,	1924 Tejon Street, Colorado Springs, Colo.	'88
*Sutcliffe, John,	Mansion Square, Poughkeepsie, N. Y.	'87
*Sutherland, J.,	B. H. Proprietary Co., Ltd., Broken Hill, New South Wales.	'92
*Sutherland, Thomas S.,	Green Island, N. Y.	'92
*Sutton, Linton B.,	Palmer, Marquette Co., Mich.	'92
†Swain, Edward A.,	39 W. 17th Street, New York City.	'86

*Swarts, William P.,	1730 W. 23d Street, Chicago, Ill.	'89
*Swasey, Ambrose,	Cleveland, Ohio.	'90
*Sweet, Henry N.,	4 Spruce Street, Boston, Mass.	'91
*Swift, George D.	Bessemer, Mich.	'93
*Swindell, William,	548 Smithfield Street, Pittsburgh, Pa.	'79
*Symington, W. N.,	Brevard, Transylvania Co., N. C.	'73
*Szontagh, Oscar,	206 Kearney Street, San Francisco, Cal.	'89
*Taft, Harry H.,	Colo. Iron Works, 33d and Wyncoop Sts., Denver, Colo.	'88
*Talbot, Benjamin,	Pencoyd, Pa.	'94
*Talbot, Henry P.,	Mass. Institute of Technology, Boston, Mass.	'88
*Tate, A. O.,	Orange, N. J.	'89
*Tatum, Lawrence W.,	Room 302, Peoples Bank Building, Denver, Colo.	'89
*Taylor, Charles,	30 Wall Street, New York City.	'87
*Taylor, Fred W.,	Apartado 132, San Luis Potosí, Mexico.	'81
*Taylor, George R.,	Robesonia Iron Co., Robesonia, Berks Co., Pa.	'92
*Taylor, Joseph J.,	P. O. Box 62, Boise City, Idaho.	'90
**Taylor, Percyvale,	21 Victoria Road, Kensington, London, W., England.	'81
*Taylor, William H.,	131 Wyoming Avenue, Scranton, Pa.	'87
*Taylor, W. J.,	High Bridge, N. J.	'75
*Tenny, Emil B.,	Missouri Furnaces, South St. Louis, Mo.	'92
*Terhune, R. H.,	P. O. Box 402, Salt Lake City, Utah.	'86
**Thacher, Arthur,	1225 Spruce Street, St. Louis, Mo.	'75
**Thacher, William A.,	180 West Street, New York City,	'90
*Thackray, George E.,	Cambria Iron Co., Johnstown, Pa.	'80
*Thayer, Benjamin B.,	P. O. Box 224, Granite, Mont.	'87
*Thielen, Alexander,	Ruhrort, Rhenish Prussia, Germany.	'91
*Thies, A.,	Haile Gold Mine P. O., Lancaster Co., S. C.	'78
*Thiry, Joseph,	Sterlington, Rockland Co., N. Y.	'92
*Thomae, W. F. A.,	"All Nations Hotel," Zeehan, Tasmania.	'93
*Thomas, D. H.,	Thomas Iron Co., Hokendauqua, Pa.	'80
†Thomas, D. M.,	80 Broadway, New York City.	'92
*Thomas, Edwin,	Thomas, Jefferson Co., Ala.	'79
*Thomas, Fred F.,	Care Willard Peck, Hudson, N. Y.	'84
*Thomas, John,	Hokendauqua, Pa.	'71
*Thomas, John M.,	Niles, Trumbull Co., Ohio.	'90
*Thomas, John W.,	Catasauqua, Pa.	'92
*Thomas, Samuel,	Catasauqua, Pa.	'71
*Thomas, Samuel R.,	Thomas Iron Co., Hokendauqua, Pa.	'92
*Thomas, William C.,	812 Madison Street, Butte, Mont.	'93
*Thomas, William R.,	Nova Scotia Gold Mines, Ltd., Montagu, Halifax Co., Nova Scotia.	'93
*Thomlinson, William,	West Hartlepool, England.	'81
*Thompson, Frank E.,	Shuler House, Pottstown, Pa.	'92
*Thompson, Heber S.,	Pottsville, Pa.	'76
*Thompson, James R.,	P. O. Box 340, Ishpeming, Mich.	'88
*Thompson, Robert M.,	37 Wall Street, New York City.	'81
*Thompson, S. R.,	Deadwood, South Dakota.	'92
*Thomson, F. du P.,	P. O. Box 524, Wilkinsburg, Pa.	'92
*Thomson, John L.,	99 Avenue B, Bayonne City, N. J.	'93
*Thurston, Prof. R. H.,	Cornell University, Ithaca, N. Y.	'75

*TIERNEY, JOHN J., ... Elkhorn, McDowell Co., W. Va. '83
*TIERNEY, L. E., ... Elkhorn, McDowell Co., W. Va. '89
*TITCOMB, EDWARD, ... Nogales, Ariz. '91
*TOBEY, HORACE P., ... West Wareham, Mass. '89
†TOEDT, EMANUEL B., ... Fairbanks Co., Albany, N. Y. '92
*TONKIN, JAMES J., Calle Doctor, No. 10, Linares, Provincia de Jaen, Spain. '93
*TONKING, JAMES B., ... Dover, N. J. '90
*TONNELÉ, THEODORE, ... McKeesport, Pa. '84
*TORRANCE, JOHN F., . . . Standard Building, Montreal, Canada. '76
*TORRENCE, JOSEPH T., ... 3646 Ellis Avenue, Chicago, Ill. '87
*TORREY, DOLPHUS, ... P. O. Box 434, St. Louis, Mo. '78
**TORREY, GRAY, ... Stirling, N. J. '90
*TORREY, H. F., ... Montclair, N. J. '93
**TORREY, HERBERT G., . . . U. S. Assay Office, New York City. '81
*TOUCEDA, ENRIQUE, . . . Troy Steel and Iron Co., Troy, N. Y. '89
*TOULMIN, PRIESTLY, ... Coalburg, Ala. '88
*TOUZEAU, E. M., . . , Leadenhall Building, London, E. C., England. '91
*TOWER, CHARLEMAGNE, JR., 243 S. Eighteenth Street, Philadelphia, Pa. '87
*TOWER, JOSEPH T., ... Poughkeepsie, N. Y. '92
*TOWNE, ROBERT S., ... 44 Pine Street, New York City. '91
*TOWNSEND, DAVID, . . . 1723 Wallace Street, Philadelphia, Pa. '80
*TOWNSEND, HENRY T., . . 216 S. Fourth Street, Philadelphia, Pa. '79
*TRASCH, HERMAN, ... Standard Block, Cleveland, Ohio. '93
*TRATMAN, E. E. R., . . . 103 Tribune Building, New York City. '91
*TRAUTVETTER, CARL, ... P. O. Box 168, Sharpsville, Pa. '90
*TREADWAY, CHARLES F., . . 174 Jennings Avenue, Cleveland, Ohio. '93
*TREADWELL, ERWIN D., . . . Keystone Mine, Amador City, Cal. '93
*TREAT, F. H., ... 50 Wabansia Avenue, Chicago, Ill. '86
*TRENT, L. C., . . 7 West Second South Street, Salt Lake City, Utah. '78
*TREWEEK, NICHOLAS, . . P. O. Box 1180, Salt Lake City, Utah. '87
*TREWENACK, W. H., . . Care Col. Mathews, Adelaide, South Australia. '91
*TRIMBLE, A. J., . . . Mallman Iron Mining Co., Duluth, Minn. '87
*TRIPPEL, ALEXANDER, ... Globe, Ariz. '83
*TROMBLEE, ANDREW, ... Port Henry, N. Y. '91
*TROTZ, J. O. EMANUEL, ... Worcester, Mass. '88
*TRUBE, G. A., ... Illinois Steel Co., South Chicago, Ill. '92
*TSUNO, T., ... Shimaneken, Japan. '91
Tunner, Peter Ritter v., ... Leoben, Austria.
*TUTTLE, ARTHUR L., ... 2727 Chestnut Street, St. Louis, Mo. '93
*TUTTLE, EDGAR G., ... P. O. Box 109, Eagle Pass, Texas. '89
*TUTWILER, E. M., ... Blossburg, Ala. '87
*TYSON, J. W., ... 301 N. Charles Street, Baltimore, Md. '86
*TYSON, JAMES W, JR., . Sixtieth Street and A. V. RR, Pittsburgh, Pa. '92

*UCHIDA, SEITARO, ... Care Takato & Co., Tokio, Japan. '90
*UDDENBERG, ARTHUR, ... Iron Mountain, Mich. '89
*UEHLING, EDWARD A., . Sloss Steel and Iron Co., Birmingham, Ala. '86
*ULRICH, GEORGE H. F., ... Dunedin, New Zealand. '90
*UNGER, J. S., ... Munhall, Pa. '91
*UPTON, L. T., ... Duquesne Steel Works, Duquesne, Pa. '93
†URIBE, ENRIQUE, ... P. O. Box 310, Berkeley, Cal. '93

*VALENTINE, M. D., ... Woodbridge, N. J. '76
*VALENTINE, S. G., ... Colbrook Furnace, Lebanon, Pa. '87
*VALTON, FERDINAND, 19 Parc de Montretout, St Cloud, Seine et Oise, France. '76
*VAN ARSDALE, W. H., ... Aurora, Ill. '72
*VAN CORTLANDT, EDWARD N., ... Pelham Manor, N. Y. '90
*VAN DIEST, E. C., ... San Luis, Costella Co., Colo. '89
*VAN DIEST, P. H., . . . 1230 Washington Avenue., Denver, Colo. '82
*VANDLING, A. H., ... Scranton, Pa. '82
*VAN MATER, JOSEPH A., . . . Franklin Furnace, Sussex Co., N. J. '93
*VAN SLOOTEN, WILLIAM, . . . 74 Wall Street, New York City. '84
*VAN WICKLE, A. S., ... Hazleton, Pa. '88
*VARDEN, RICHARD A., . . { Constitutional Club, Northumberland Avenue, London, England. '87
*VAUTIN, CLAUDE, . . 42 Old Broad Street, London, E. C., England. '90
*VEEDER, HERMAN, ... Care Hussey & Co., Pittsburgh, Pa. '80
*VEZIN, HENRY A., ... P. O. Box 256, Denver, Colo. '74
*VIGGERS, WILLIAM, ... Durango, Mexico. '89
*VIVIAN, CHARLES, ... Brewster, N. Y. '91
*VIVIAN, GEORGE G., ... Idaho Springs, Colo. '82
*VOLCKENING, G. J., JR., . . 675 Lafayette Avenue, Brooklyn, N. Y. '91
*VON LEICHT, F., ... Mirabel, Lake Co., Cal. '89
†VON ROSENBERG, LEO, ... 35 Broadway, New York City. '91
*VON STEYERN, BALTZAR, ... Falun, Sweden. '85

*WADSWORTH, H. L., . . 1209 Seventeenth Street, Denver, Colorado. '89
*WADSWORTH, M. E., Dr., . Michigan Mining School, Houghton, Mich. '89
*WAGNER, E. C., ... Girardville, Pa. '85
*WAGNER, JOHN R., ... Drifton, Pa. '91
*WAINWRIGHT, JACOB T., ... P. O. Box 434, Chicago, Ill. '88
*WAIT, PROF. CHARLES E., . University of Tennessee, Knoxville, Tenn. '79
*WALCOTT, C. D., . . . U. S. Geological Survey, Washington, D. C. '92
*WALCOTT, R. H., Tech. Museum, Swanston Street, Melbourne, Australia. '93
*WALDO, DR. LEONARD, ... Bridgeport, Conn. '88
*WALKER, ARTHUR L., . . { Baltimore Elec. and Ref. Co., Keyser Building, Baltimore, Md. '85
*WALKER, HARRY F., ... Paterson, N. J. '91
*WALKER, J. C., ... 2910 Groveland Avenue, Chicago, Ill. '83
†WALKER, JOHN A., . . Joseph Dixon Crucible Co., Jersey City, N. J. '78
†WALKER, JOSEPH R., ... Salt Lake City, Utah. '85
*WALKER, PERCY H., ... P. O. Box 1783, Iowa City, Iowa. '92
*WALKER, ROBERT L., . . . 317 Lewis Block, Pittsburgh, Pa. '91
*WALKER, T. B., Monongahela Furnace Co., P. O. Box 261, McKeesport, Pa. '84
*WALKER, W. R., ... Illinois Steel Co., South Chicago, Ill. '81
*WALL, E. A., ... Ophir, Utah. '87
**WALLER, DR. ELWYN, . . . Columbia College, New York City. '83
†WALLER, G. A., ... Freiberg, Saxony, Germany. '94
*WALLIS, PHILIP, ... Care C. B. & Q. R.R., Roanoke, Va. '84
*WALSH, EDWARD, JR., . . Main and Angelica Streets, St. Louis, Mo. '74
*WALTER, E. W., ... Public Samplings Works, Silverton, Colo. '93
*WANNER, JOHN P., ... P. O. Box 43, Johnstown, Pa. '92
*WARD, WILLARD P., ... Mills Building, New York City. '71

*Ward, William Shaw, . . . 1280 Grant Avenue, Denver, Colo. '94
*Warne. H. H., ... Guston, Ouray Co., Colo. '89
*Warner, Willard, Jr., ... Rockwood, Tenn. '92
†Warren, Charles S., ... 615 Rookery, Chicago, Ill. '87
*Warren, George H., . 3443 Irving Avenue, South Minneapolis, Minn. '91
*Warren, George Henry, Jr., . . . 28 State Street, New York City. '81
*Warriner, Samuel Dexter, ... Wilkes-Barre, Pa. '91
**Wartenweiler, Alfred, ... Butte, Mont. '75
*Waterman, H. L., ... 44 Wall Street, New York City. '81
*Waters, Albert L., ... Blue Spring, Bradley Co., Tenn. '93
*Waters, Thomas J., ... Sheriden Building, Denver, Colo '86
*Watson, Benjamin C., ... Huantla, Estado Morelos, Mexico. '89
*Watson, Fred. M., . . Care Backus & Johnson, Lima, Peru, S. A. '87
*Watson, Ralph W., ... Great Falls, Mont. '90
†Waugh, Percival Bentley, . Rio Tinto Co., Limited, Huelva, Spain. '90
*Weaver, H. B., ... 353 Union Street, Allentown, Pa. '92
*Webb, H. H., ... Selby, Contra Costa Co., Cal. '85
*Webb, H. Walter, . Vanderbilt Avenue and 44th Street, New York City. '82
*Webster, H. L., ... Johannesburg, Transvaal, So. Africa. '92
*Webster, John, 56 Lillieshall Road, Clapham, London, S.N., England. '93
*Webster, William R., . . 3310 Hamilton Street, Philadelphia, Pa. '92
Wedding, Prof. Dr. Hermann, ... Berlin, Germany.
*Weeks, Joseph D., ... P. O. Box 591, Pittsburgh, Pa. '75
*Weimer, Asa A., ... Lebanon, Pa. '85
*Weimer, John A., ... Lebanon, Pa. '85
*Weimer, John P., ... 337 King Street, Pottstown, Pa. '92
*Weir, Thomas, ... P. O. Box 1302, Salt Lake City, Utah. '90
*Weis, Moriz, ... Sparrow's Point, Md. '91
*Wellman, Charles H., ... Thurlow, Pa. '90
*Wellman, Reno B., . . Wellman Iron and Steel Co., Thurlow, Pa. '93
**Wellman, S. T., ... Upland, Delaware Co., Pa. '75
†Wells, Calvin, . . . Pittsburgh Forge and Iron Co., Pittsburgh, Pa. '73
*Welsh, Howard F., ... Hartranft, Tenn. '91
*Wenström. Olaf, ... Harlow Block, Marquette, Mich. '88
*Werther, Francis O., . . . 318 N. Third Street, Pottsville, Pa. '93
*Westinghouse, George, Jr., ... Pittsburgh, Pa. '86
*Western, Charles R., . . . { Broadway Chambers, Westminster, London, England. '92
*Weston, Francis E., ... Upland, Pa. '85
*Wethey, A. H., ... P. O. Box 505, Butte, Mont. '90
*Wetmore, E. A., ... Marquette, Mich. '89
*Wheeler, Earl A., ... Sharon, Pa. '91
**Wheeler, H. A., . . . Washington University, St. Louis, Mo. '81
*Wheeler, S. B., ... Chestnut Hill, Philadelphia, Pa. '92
*Wheelock, Jerome, ... Worcester, Mass. '82
*Whinery, S., ... 23 Blymyer Building, Cincinnati, Ohio. '80
*Whitaker, Thomas D., ... P. O. Box 65, Easton, Pa. '92
*Whitcomb, George D., . Dearborn and Monroe Streets, Chicago, Ill. '83
*Whitehead, Cabell, 1114 New Hampshire Avenue, Washington, D. C. '90
*White, Maunsel, ... Bethlehem, Pa. '88
†White, Peter, ... Marquette, Mich. '94

*White, Robinson T.,	393 E. Park Street, Butte, Mont.	'93
*Whiteley, James S.,	Rialto Building, 409 Water Street, Baltimore, Md.	'92
*Whiting, Jasper,	Care Illinois Steel Co., Chicago, Ill.	'91
*Whiting, Henry A.,	P. O. Box 804, Wilmington. N. C.	'85
*Whiting, S. B.,	Calumet, Lake Superior, Mich.	'71
*Whitmore, L. H.,	23 Bucklersbury, London, E. C., England.	'90
*Whitney, Eli, Jr.,	Whitneyville Armory, New Haven, Conn.	'75
*Whitney, Granger,	99 E. Fort Street, Detroit, Mich.	'91
*Wickes, George T.,	Helena, Mont.	'76
*Wilbur, R. H.,	So. Bethlehem, Pa.	'86
*Wilbur, Warren A.,	Northampton Iron Co., South Bethlehem, Pa.	'92
*Wilcox, John F.,	86 Lewis Block, Pittsburgh, Pa.	'86
*Wiles, Edwin L.,	Riverside Iron Works, Wheeling, West Va.	'82
*Wiley, H. W.,	Department of Agriculture, Washington, D. C.	'93
*Wiley, William H.,	53 East Tenth Street, New York City.	'81
*Wilkes, John,	Charlotte, N. C.	'83
*Wilkins, Henry A. J.,	Franklin Furnace, N. J.	'92
*Wilkins, Ross,	85 Trumbull Street, Detroit, Mich.	'86
*Wilkins, William,	P. O. Box 25, Port Kennedy, Pa.	'91
*Wilkins, William Glyde,	Westinghouse Building, Pittsburgh, Pa.	'91
*Wilkinson, J. F.,	New Almaden, Cal.	'90
**Wilkinson, William F.,	Peterboro House, Harrow, London, England.	'88
*Willey, Stansbury J.,	1010 King Street, Wilmington, Del.	'92
*Williams, Ben.,	Bisbee, Ariz.	'82
*Williams, David,	43 E. Sixty-seventh Street, New York City.	'80
*Williams, Prof. Edward H., Jr.,	117 Church Street, Bethlehem, Pa.	'76
*Williams, E. H.,	Brown, Bonnell Iron Co., Youngstown, Ohio.	'93
*Williams, Frank,	34 Conestoga Building, Pittsburgh, Pa.	'88
**Williams, Gardner F.,	De Beers Consolidated Mines, Ltd., Kimberley, So. Africa.	'86
*Williams, Henry,	Butte, Mont.	'75
*Williams, Henry J.,	161 Tremont Street, Boston, Mass.	'87
*Williams, H. J. C.,	Care J. McDonald, 43 Threadneedle Street, London, E. C., England.	'93
*Williams, Henry S.,	Cornell University, Ithaca, N. Y.	'86
*Williams, John I.,	Youngstown, Ohio.	'92
*Williams, John T.,	54 Franklin Street, New York City.	'74
*Williams, Lewis,	Bisbee, Ariz.	'83
*Williams, Luke,	304 Murray Street, Hobart, Tasmania.	'93
*Williams, Morris,	Shamokin, Pa.	'91
*Williams, Oliver,	Catasauqua, Pa.	'87
*Willis, Bailey,	U. S. Geological Survey, Washington, D. C.	'92
*Willis, Charles E.,	Halifax Hotel, Halifax, Nova Scotia.	'89
*Wills, Joseph L.,	Care Dr. Francis Wyatt, 12 Old Slip, New York City.	'89
*Willsie, Myron,	Rapid City, So. Dakota.	'87
*Wilson, Benjamin C.,	Waverly, Nova Scotia.	'89
*Wilson, Elliott H.,	Butte, Mont.	'87
*Wilson, Eugene B.,	Elkhorn, McDowell Co., W. Va.	'83
*Wilson, Harold,	Silverton, Colo.	'92
*Wilson, Harry,	Broken Hill Prop. Co., Broken Hill, New South Wales.	'93
*Wilson, John A.,	Drexel Building, Room 1036, Philadelphia, Pa.	'76

*Wilson, Joseph M., ... No. Third Street, Steubenville, Ohio. '82
*Wilson, Joseph R., ... Shawmont, Philadelphia, Pa. '94
†Wilson, M. O., ... 33 Wall Street, New York City. '91
**Wilson, N. R., ... Apartado 38, Monterey, Mexico. '81
†Wilson, R. T., Jr., ... 33 Wall Street, New York City. '91
*Wilson, William A., . . University Club, Salt Lake City, Utah. '83
*Wilson, Walter B., ... P. O. Box 180, Silverton, Colo. '92
*Wiltsee, E. A., . Care Barnato Bros., Johannesburg, Transvaal, So. Africa. '86
*Winchell, Horace V., . 1306 S. E. Seventh Street, Minneapolis, Minn. '92
†Winter, James, 30 Hadfield Street, Georgetown, Demerara, British Guiana. '93
*Winslow, Arthur, . Roe Building, Fifth and Pine Streets, St. Louis, Mo. '81
*Wishon, Walter W., ... P. O. Box 773, Butte, Mont. '82
*Wister, Francis, ... Bullitt Building, Philadelphia, Pa. '86
*Wister, Jones, ... 257 S. Fourth Street, Philadelphia, Pa. '79
*Witherbee, Frank S., ... Port Henry, Essex Co., N. Y. '76
**Witherbee, T. F., ... Port Henry, Essex Co., N. Y. '71
*Witherbee, W. C., ... Port Henry, Essex Co., N. Y. '80
*Wittman, N. B., ... Birdsboro, Pa. '84
*Woakes, Ernest R., . . . 78 Harley Street, London, W., England. '89
*Wolf, Theodore G., ... Scranton, Pa. '79
*Wolfe, Albert H., . . Insurance Exchange Building, Chicago, Ill. '82
**Wolff, Dr. Fr. M., . . 12 Hohenzollernstrasse, Berlin, West, Prussia. '82
*Wolle, Hartley C., ... Bethlehem, Pa. '86
*Wood, A. B., ... 980 Jefferson Avenue, Detroit, Mich. '82
*Wood, E. Fred., ... P. O. Box 23, Munhall Pa. '86
*Wood, Howard, ... Conshohocken, Pa. '88
*Wood, James G., ... Bote Mining Co., Zacatecas, Mexico. '93
*Wood, Thomas D., ... McKeesport, Pa. '79
*Wood, Tingley S., ... P. O. Box 556, Leadville, Colo. '89
*Wood, Walter, ... 400 Chestnut Street, Philadelphia, Pa. '85
†Wood, W. Dewees, ... 111 Water Street, Pittsburgh, Pa. '83
**Woodbridge, T. R., ... 639 17th Avenue, Denver, Colo. '87
*Woodbury, L. S., . . Great Falls Iron Works, Great Falls, Mont. '80
*Woodhouse, Alfred, . . Bremgarten, Woking, Surrey, England. '87
*Woodward, Henry E., ... Aspen, Colo. '89
†Woodward, H. G., ... Clarksville, Tenn. '86
*Woodworth, George L., ... Marmora, Ontario, Canada. '92
*Worthington, Charles C., . . . 145 Broadway, New York City. '85
*Wotherspoon, Henry H., Jr., 334 W. Nineteenth Street, New York City. '92
*Wright, James N., . . . 34 E. Warren Avenue, Detroit, Mich. '79
**Wright, Whitaker, . . . P. O. Box 1784, San Francisco, Cal. '81
**Würgler, A., ... 7 rue Viète, Paris, France. '85
*Wyatt, Francis, ... 12 Old Slip, New York City. '87

*Yamada, Kinichi, . . Care Senba Kawashima, Uagi, Nagato, Japan. '87
*Yardley, Thomas W., ... 631 The Rookery, Chicago, Ill. '83
*Yeatman, Pope, . . . Room 79, 904 Olive Street, St. Louis, Mo. '83
*York, James E., . . . 308 Lyceum Building, Duluth, Minn. '87
*Young, Edward L., . . 317 W. Eighty-ninth Street, New York City. '87
**Young, James B., ... South Atlanta, Ga. '79
*Young, J. W. R., ... Ahualulco, Jalisco, Mexico. '91

*Zehnder, C. H.,	Berwick, Pa.	'87
*Zellenkoff, Eugéne de,	Zellenkoff Gold Mine, Kotschkarsh, Orenburg, Russia.	'91
*Zerbey, Frederick E.,	Lost Creek, Pa.	'92
†Zukoski, Charles F.,	823 Washington Avenue, St. Louis, Mo.	'86
*Zukoski, Edmund L.,	2340 Whittemore Place, St. Louis, Mo.	'84

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Deceased.

Amiot, H.,	1892	De Camp, Edw. F.,	1891
Arnolds, Hugo,	1886	De Peiger, R. F. J.,	1883
Ashburner, Charles Albert,	1889	Dickson, Thomas,	1884
Ashburner, William,	1887	Dresser, Charles A.,	1878
Atkins, C. M., Jr.,	1885	Dwight, W. S.,	1883
Babcock, Geo. H.,	1893	Ely, George H.,	1894
Bailey, Edward,	1889	Emerson, B. F.,	1887
Bailey, Jackson,	1887	Fegeley, Isaac,	1891
Barnes, F. W.	1892	Felton, S. M.,	1889
Babratt, D. H.,	1888	Fernekes, Anton,	1884
Becher, H M.,	1893	Firmstone, William,	1877
Beeger, H.,	1892	Fisher, Harvey,	1885
Bell, G. B.,	1893	Fisher, H. H.,	1889
Billing, G.,	1890	Foote, Herbert C.,	1888
Blake, F. C.,	1891	Ford, Robert G.,	1890
Blossom, T. M.,	1876	Francis, A. G.,	1891
Boyle, Thomas G.,	1890	Fuller, John T.,	1880
Braden, S.,	1894	Gatewood, R.,	1890
Brainerd, A. F.,	1893	Goodwin, H. S.,	1892
Briggs, Robert,	1882	Gould, Robert A.,	1878
Brinsmade, J. B.,	1884	Gowen, Franklin B.,	1889
Brown, A. C.,	1890	Graham, Thomas,	1892
Brown, A. J.,	1875	Gridley, Edward,	1887
Browning, F. D.,	1885	Griffen, John,	1884
Bruckner, Wm.,	1887	Gruner, L.,	1883
Brunings, J. H,	1893	Gurley, William,	1887
Bunsen, Robert,	1887	Hahn, Ignatius,	1888
Butler, Cyrus,	1890	Hall, James F.,	1884
Caldwell, W. B., Jr.,	1880	Harnickell, A.,	1887
Cameron, James R.,	1881	Harris, Stephen,	1874
Carnegie, Thomas M.,	1886	Hart, W. R.,	1892
Carroll, Michael,	1891	Hartung, Max J.,	1894
Cheever, B. W.,	1888	Harvey, William H.,	1888
Chisholm, Henry,	1881	Healy, Morris,	1881
Clark, Henry G.,	1881	Heinrich, Oswald,	1886
Clark, R. Neilson,	1894	Henry, Adolph,	1892
Clark, William,	1884	Hicks, Geo. J.,	1891
Clayton, Joshua,	1889	Hillman, Daniel,	1890
Clayton, W. S.,	1886	Holley, A. L.,	1882
Clemes, J. P.,	1876	Hollister, O. J.,	1892
Conant, T. P.,	1891	Hopke, Frank E.,	1890
Converse, James B.,	1883	Horton, N. W.,	1886
Cook, George H.,	1886	Hulbert, Thomas H.,	1889
Coryell, Martin,	1892	Humphreys, A. W.,	1894
Cowles, E. H.,	1892	Hunt, Joshua,	1886
Craven, Frank S.,	1889	Hunt, Thomas,	1872
Craven, Henry S.,	1889	Hunt, T. S.,	1892
Crocker, William B.,	1885	Hussey, C. C.,	1884
Daddow, S. H.,	1875	Hyndman, E. K.,	1884
D'Aligny, H. F. Q.,	1875	Ingersoll, S. Warren,	1884
Darling, J. V.,	1892	Irving, R. D.,	1888
Davidson, D. R.,	1884	Irwin, John H.,	1890
Davies, Edw. S.,	1885	James, Isaac E.,	1887
Davies, W. B.,	1891	Jenney, F. B.,	1876
Davis, M. C.,	1886	Jernegan, J. L.,	1881
Dayton, L. M.,	1892	Johnston, W. N.,	1886

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JONES, W. R.,	1889	POTES, J. D.,	1893
KELLY, G. D.,	1892	PRICE, E. A.,	1893
KERR, PROF. W. C.,	1885	PRICE, J. A.,	1892
KREISCHER, C. G.,	1891	PRIEST, J. R.,	1880
KRIETE, HENRY C.,	1890	PRINCE, F.,	1892
KURIMOTO, REN,	1892	RAMSAY, M.,	1892
LANDSBERG, E.,	1888	REED, H. L.,	1893
LAVALEYE, E. DE,	1892	RICHTER, C. E.,	1877
LEE, R. H.,	1892	RICKARD, R. H.,	1885
LEE, WASHINGTON,	1872	RIDER, W. E.,	1892
LEISENRING, JOHN,	1874	RINGELING, FRANK,	1893
LEWIS, DAVID B.,	1867	RIOTTE, EUGENE N.,	1891
LIEBENAU, CHARLES VON,	1875	ROBINSON, L. L.,	1892
LIENAU, D. B.,	1890	ROBINSON, THOMAS W.,	1880
LOBDELL, GEO. G.,	1894	ROGERS, A. N.,	1890
LOISEAU, E. F.,	1886	SANTA MARIA, RAYMUNDO DE,	1883
LORD, JOHN C.,	1872	SAVAGE, E. G.	1891
LORENZ, W.,	1884	SAYLOR, DAVID O.,	1884
LORENZ, W., JR.,	1881	SCHAUFUSS, E. C.,	1889
LOWE, FRANCIS A.,	1883	SCHIRMER, J. F. L.,	1877
MCGENNIS, J. W.,	1891	SCHLINK, T.,	1893
MCINTIRE, HENRY M.,	1880	SCHMALENSÉE, CARL VON,	1887
MCKEE, DAVID,	1884	SCHUCHARD, CHARLES,	1883
MACKINTOSH, J. B.,	1891	SCRANTON, W. H.,	1889
MACKINTOSH, W. S.,	1884	SHEAFER, P. W.,	1891
MACLEAN, F. P.,	1891	SHINN, W. P.,	1892
MACMARTIN, ARCHIBALD,	1881	SICKLES, T. E.,	1885
MACY, ARTHUR,	1891	SIEMENS, C. WILLIAM,	1883
MAFFET, W. R.,	1891	SILLIMAN, PROF. B.,	1885
MANNESS, CHARLES F.,	1887	SLADE, F. J.,	1891
MANTHEY, WILLIAM,	1883	SMALLEY, W. A.,	1886
MARCH, W. J.,	1891	STEITZ, AUGUSTUS,	1876
MATTHEWS, C. W.,	1891	STERLING, HENRY S.,	1882
MAURY, M. F.,	1886	STINSON, JOHN M.,	1884
MERCUR, FREDERICK,	1888	ST. JOHN, I. M.,	1880
MICHAELIS, O. E.,	1890	STOCKWELL, N. S.,	1888
MICKLEY, J. W.,	1880	STODDER, R. H.,	1889
MILLER, REUBEN,	1890	STOELTING, HERMANN,	1875
MOFFAT, E. S.,	1893	STOLLMEYER, A. B.,	1890
MOORE, CHARLES W.,	1877	STONE, GEN. CHARLES P.,	1887
MORGAN, J.,	1892	STONE, G. G.,	1893
NEWTON, HENRY,	1877	STRAKER, TOOKE,	1892
NEWTON, ISAAC,	1884	SYMONS, W. R.,	1888
NICHOLS, EDW.,	1892	TEFT, WALTER,	1885
NICHOLSON, A. H.,	1887	THAW, WM., JR.,	1892
NOBLE, SAMUEL,	1888	THOMAS, DAVID,	1882
NORTON, F. O.,	1893	THOMAS, SIDNEY G.,	1885
O'FARRELL, JOHN J.,	1888	THOMPSON, PROF. C. O.,	1885
OLIVER, WILLIAM,	1890	THONARD, LEON,	1886
OWEN, J. R. D.,	1887	TILEMAN, JOHN N.,	1888
PAINTER, HOWARD,	1876	TOWER, A.,	1891
PARK, JAMES, JR.,	1883	TROILIUS, M.,	1886
PARKER, O. B.,	1891	TUTTLE, H. A.,	1888
PATERA, ADOLPH,	1890	VAN TUYLL, C. B.,	1890
PERCY, JOHN,	1889	VAN ZANT, F.,	1892
PETTIBONE, AUGUSTUS,	1890	WAITHMAN, HUBERT,	1891
PHELPS, WALTER,	1878	WALKER, W. J. B.,	1894
PHILLIPS, P. E.,	1884	WALTER, T. FRANK,	1888
PIERSON, O. H.,	1882	WALZ, ISIDOR,	1877
PLATT, W. G.,	1885	WARNER, L. E.,	1884

Waters, J. H. E.,	1893	Wiestling, G. B.,	1891
Watts, D.,	1893	Wilcox, S.,	1893
Welch, Ashbel,	1882	Williams, J. J.,	1892
Wells, Bard,	1893	Wilson, J. W.,	1894
Wendel, Dr. A.,	1881	Witherbee, J. G.,	1875
Wendt, A. F.,	1893	Wood, Wm. J.,	1885
Wheatley, Charles M.,	1882	Worthington, Henry R.,	1880
Wheeler, Moses D.,	1889	Wright, Charles E.,	1888
West, A. R.,	1893	Wright, Harrison,	1885
Whilldin, W. I.,	1882	Wrigley, H. E.,	1882
White, James B.,	1887	Wurts, C. P.,	1892

LIST OF MEMBERS AND ASSOCIATES ARRANGED ACCORDING TO STATES AND TOWNS.

ALABAMA.

Aldrich, Aldrich, W. F. *Anniston*, King, Noble, S. N., Peacock. *Avondale*, McCune. *Bessemer*, Johns. *Birmingham*, Forker, McCormack, Meissner, Montgomery, J. A., Phillips, Seddon, Sloss, Smith, N. B., Uehling. *Blocton*, Cadle. *Blossburg*, Tutwiler. *Brookside*, Campbell, E. S., Jr. *Brookwood*, Jackson, F. N. *Coalburg*, Toulmin. *Ensley*, Skelding. *Helena*, Squire, J. *Heflin*, Brewer. *Jenifer*, Noble, A. E. *Pratt Mines*, Ramsay, E., Reilly. *Rock Run*, Garvin. *Sheffield*, Doud. *Thomas*, Thomas, E. *University*, McCalley.

ALASKA.

Juneau City, Garside, Geo. W.

ARIZONA.

Bisbee, Beckwith, Williams, B., Williams, Lewis. *Clifton*, Jones, E. P., Smith, J. D. A. *Copper Basin*, Rogers, A. H. *Curtiss*, Mills, C. E *Flagstaff*, Riordan. *Globe*, Trippel. *Harqua Hala*, Allen, Theophilus. *Hillside*, Armitage. *Mammoth*, Barnhart. *Nogales*, Titcomb. *Oro Blanco*, Kempton. *Phœnix*, Clark, E., Jr., Nicholson. *Prescott*, Blandy, Blauvelt, H., Curry, G. H., Edwards, H. W., Morse, W. S. *Tombstone*, Earle, Goodwin, Staunton. *Tucson*, Comstock, T. B. *Yarnell*, Campbell, J. H.

ARKANSAS.

Little Rock, Morrison, W. W.

CALIFORNIA.

Alameda, Arents, A., Connor, S. B., Merrill, E. W. *Amador City*, Call, Myers, J., Treadwell. *Berkeley*, Booth, F., Christy, Escobar, M., Patterson, W. E., Rickard, R., Uribe, E. *Bodie*, Leggett. *French Gulch*, Clark, C. J. *Grass Valley*, Abadie. *Grub Gulch*, Kaufman, C. *Ivanpah*, Godbe. *Johnsville*, Cheyney. *Los Angeles*, Plater. *Maybert*, Huhn. *Mirabel*, Von Leicht. *Needles*, Amsden, O. B. *New Almaden*, Wilkinson, J. F. *Oakland*, Merrell, J. M., Miller, W. P., Jr., Stetefeldt. *Palo Alto*, Branner. *Quincy*, Mills, J. E. *San Ardo*, Lathrop, M. A. *San Francisco*, Bowie, A. J., Jr., Bratnober, Brown, R. E., Clark, M., Corning, C. R., Cross, Crawford, Davis, A. B., Edwards, W. S., Emmens, Gillette, Gilson, Hammond, J. H., Hasson, Holman, Janin, A., Janin, L., Keyes, Oothout, Price, Ralston, Randol, Reddy, Rickard, T., Jr., Robinson S., Shockley, Stevenson, R., Striedinger, Szontagh, Wright, W. *Selby*, Webb, H. H. *Victor*, Pedley. *Visalia*, Small, G. W. *Weaverville*, Radford.

COLORADO.

Argo, Pearce. *Aspen*, Bardwell, Brunton, Bulkley, Frank, Bulkley, F. G., Cox, W. J., Devereux, J. H., Freeland, Hare, Hawkins, J. D., Little, Loane, Miller, C. W., Newberry, Richards, J. W., Strickland, Woodward, H. E. *Barry*, Bray. *Buena Vista*, Holthoff. *Central City*, Locke, B. H., Rickard, F. *Colorado Springs*, Banon, Bolles, J. H., Bolles, R. J., Dickerman, Hagerman, Palmer, C. E., Strieby, Surls. *Creede*, Field, J., Macnutt, C. H. *Cripple Creek*, Countryman. *Denver*, Akers, Argall, P., Austin, W. L., Blow, Burlingame, Burlingham, Cazin, F., Chanute, A., Cowland, Danforth, Davis, W. C., Eames, J. C., Emanuel, Farish, Foster, E. Le Neve, Furman, Gorham, Grant, Hale, I., Kebler, J. A., Kirby, Lacombe, Lawrence, B. B., Livingston, Middleton, Munson, Page, W. B., Paul, Porter, J. A., Rich, F. A., Rickard, A.,

Rickard, T. A., Rogers, E. M., Rollins, Schwarz, T. E., Shields, C. O., Smith, M. E., Stearns, T. B., Taft, Tatum, Van Diest, Vezin, Wadsworth, H. L., Ward, W. S., Waters, T. J., Woodbridge. *Dubois*, Sperry, E. A. *Durango*, Amy, Keller, A. H., Mercer, Nickels. *Georgetown*, Dewey, C. E., Griffin, H. M., Martine. *Glenwood Springs*, Devereux, W. B. *Guston*, Harvey, Warne. *Idaho Springs*, Dumont, Vivian, G. C. *Leadville*, Boehmer, Bretherton, S. E., Carnahan, Coleman, R. J., Judkins, Moore, C. J., Mudd, Noble, L. S., Rhodes, R. D., Wood, T. S. *Lenado*, McCann, F. *Ouray*, Kedzie. *Pitkin*, Johnson, F. M. *Pueblo*, Allen, W. W., Dwight, A. S., Eakins, Eilers, K., Goodell, Holt, M. B., Johnson, E. W., Knapp, E. E., Mathewson, Mattes, Raht, Robinson, C. S., Robinson, T. W. *Rico*, Edwards, J. W. *San Luis*, Van Diest, E. C. *Silverton*, Ingersoll, Stoiber, Walter, Wilson, Harold, Wilson, W. B. *Sunset*, Sperry, J. A. *Telluride*, Lay. *Trinidad*, Hofius. *Ward*, Kenyon.

CONNECTICUT.

Ansonia, Farrel, F. *Branford*, Hammer, A. E. *Bridgeport*, Waldo. *Chapinville*, Starr, J. *Colkinsville*, Sears. *Hartford*, Loomis. *New Haven*, Blake, T. A., Blake, W. P., Brush, Du Bois, A. J., Whitney, E., Jr. *Saugatuck*, Ketchum. *Stamford*, Dickinson, W. E., Payne, C. Q. *Waterbury*, Morse, C. S.

DELAWARE.

Wilmington, Barksdale, Griffiths, H. B., Haskell, J. A., Haskell, H. G., Morse, H. G., Willey.

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Washington, Barber, Beck, W. H., Becker, Bigelow, W. D., Bradley, G. L., Campbell, M. R., Chatard, Darton, Day, Dewey, F. P., Eldridge, G. H., Emmons, S. F., Fernow, Gilbert, G. K., Hague, Hayes, C. W., Hesse, Hewett, Hill, R. T., Hollerith, Ladd, Leech, McElroy, McGee, Mendenhall, Newell, F. H., Packard, Parker, E. W., Partridge, Pennie, Powell, Richards, Edgar, Rosecrans, Rosell, Smith, B., Walcott, C. D., Whitehead, Wiley, H. W., Willis, B.

FLORIDA.

Bartow, Codington, Huntington. *Boyd*, Pickford. *Eagle Mines*, Potts, G. E. *Ocala*, Richè. *St. Augustine*, MacGonigle.

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Hollis, Holmboe, Hoskins, Hunt, R. W., Jewell, Kraft, Loveland, Mackay, A., McClure, R. J., Macomber, Merryweather, Miller, C. L., Mitting, Mohr, Morison, Morse, J. C., Moss, Osgood, Parkes, Parkhurst, Peck, Penfield, Potter, E. C., Potter, O. W., Prentiss, Reed, S. A., Sellers, M., Skiff, Smith, H. S., Smith, W. S., Stirling, Stonestreet, Swarts, Torrence, J. T., Treat, Walker, J. C., Warren, C. S., Whitcomb, Whiting, J., Wolfe, Yardley. *South Chicago*, Bartlett, G. B., Brown, S. L., Clarke, E. A. S., Church, T. V., Doney, Foote, F. H., Julian, Kellogg, McCullough, Moynau, Pelouze, Rhodes, F. B. F., Smith, M., Sauveur, Souther, Trube, Walker, W. R. *Joliet*, Conlin, Garrett, W., Hyde, Pettigrew. *La Salle*, Engelmann, Hegeler, E. C., Hegeler, J. W., Matthiessen, Stoddard. *Oak Park*, Lane. *Peru*, Means, A. *Rockford*, Forbes, Mead, D. W. *Springfield*, Griffiths, J., Ridgely, C., Ridgely, W. B. *Spring Valley*, Gluck. *Streator*, Cherry. *Urbana*, Baldwin.

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Alexandria, Lippincott, J. E. *Connersville*, Johnston *Indianapolis*, Edwards, J. P. *Mishawaka*, Dodge, W. H.

INDIAN TERRITORY.

Hartshorne, Ludlow, E.

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Des Moines, Ballard. *Iowa City*, Walker, P. H.

KANSAS.

Argentine, Alexander, C., Canby, Huber, Rockwell, Ruetschi. *Lansing*, Lamm.

KENTUCKY.

Ashland, Kemler, Means, E. C. *Covington*, Breckenridge. *Cloverport*, Inglis. *Grand Rivers*, Searle. *Louisville*, Macfarlane. *Middlesborough*, Bartlett, J. H. *Olympia*, Dickerson.

LOUISIANA.

Cypremont, Oxnard. *New Iberia*, Pomeroy, R. A. *New Orleans*, Black, A. L., Carroll, Claussen, Evans, M. W., Ordway.

MAINE.

Portland, Peters, S. *Yarmouthville*, Hammond, G. W.

MARYLAND.

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MASSACHUSETTS.

Acton, Crooker. *Boston*, Atherton, Bigelow, A. S., Billings, Browne, A. B., Drake, F., Drown, Eustis, Fletcher, C. R., Foucar, Hodges, A. D., Jr., Hofman, H. O., Howe, H. M., Hunt, W. P., Jr., Locke, Lodge, R. W., Parsons, C. O., Pechin, J. S., Pope, T. E., Rice, G. S., Richards, Ellen H., Richards, R. H., Sharples, Stearns, G. H. Sweet, Talbot, H. P, Williams, H. J. *Brookline*, Cabot. *Cambridge*, Agassiz, Sayr, Smyth, H. L. *Cambridgeport*, Leavitt, E. D. *Dorchester*, Lanning, Peters, E. D., Jr. *Fall River*, Almy, W. F. *Fitchburg*, Crocker, K. F. *Lynn*, Darling. *Melrose*, Norris, G. L. *New Bedford*, Bassett, Hathaway, Shirley. *Roxbury*, Pearse. *Springfield*,

Hewitt, G. H. *Wakefield*, Packard, G. A. *West Wareham*, Leonard, W. A., Tobey. *Worcester*, Bildt, Daniels, Forsstedt, Fuller, H. G., Moen, Morgan, C. H., Schmiterlow, Trotz, Wheelock.

MICHIGAN.

Alpena, Jones, R. A. *Amasa*, Lawrence, C. E. *Ann Arbor*, Campbell, E. D., Jaycox, Pettee. *Atlantic Mine*, Stanton, F. M. *Bessemer*, Bennett, Swift. *Calumet*, Duncan, J., Hoatson, T., Whiting, S. B. *Detroit*, Brady, S., Courtis, Gerhauser, Keep, Plumb, Russel, W. S., Whitney, G., Wilkins, R., Wood, A. B., Wright, J. N. *Grand Rapids*, Holt, J. C. *Houghton*, Croze, Denton, F. W., Edwards, R. M., Koenig, Mason, R. T., Sharpless, Wadsworth, M. E. *Iron River*, Jones, J. T. *Iron Mountain*, Brewster, E. E., Brown, E. F., Channing, Flaherty, Jones, J. T., McNaughton, Uddenberg. *Ironwood*, Jennings, E. P. *Ishpeming*, DuBois, H. W., Mills, F. P., Parnall, Thompson, J. R. *Lake Linden*, Coggin, F. G., Heath. *Mancelona*, Duncan, M. M. *Marquette*, Cummings, G. P., Jopling, J. E., Palmer, E. V., Parker, R. A., Wenström, Wetmore, E. A., White, P. *Michigamme*, Fowle. *Negaunee*, Cole, T. F., Farrell, A., Saunders. *Norway*, Larsson. *Palmer*, Ball, E., Lawton, Sutton. *Republic*, Forsberg. *Rockland*, Chynoweth. *Vulcan*, Kelly, W.

MINNESOTA.

Biwabik, Armstrong, J. F. *Duluth*, Howe, C. F., Lammers, La Rue, Mallman, Olcott, W. J., Riebel, Sebenius, Trimble, York. *Ely*, Gilbert, E. J. *Hibbing*, Honnold, Longyear. *Minneapolis*, Appleby, Burt, H. E., Crocker, A. L., Ferguson, S. T., Warren, G. H., Winchell. *St. Paul*, Conradson, Estabrook. *Soudan*, Bacon, D. H. *Tower*, Morcum. *Two Harbors*, McGonagle. *Virginia*, Green, R. B.

MISSOURI.

Bonne Terre, Parsons, C. B., Setz. *Carthage*, Ihlseng. *Crystal City*, Neale. *Desloge*, Dealoge. *Doe Run*, Bilharz, Graves, F. P. *Gregg*, Hedburg. *Kansas City*, Meyer. *Midland*, Kolbe. *Mine La Motte*, Monell, Sanders, J. D. *Rolla*, Landis, H. K., Seamon. *Sligo*, Foote, E. L. *Springfield*, Herndon. *St. Louis*, Chauvenet, W. M., Chouteau, Crawford, H. A., Fordyce, Francis, A., Frink, Fusz, Gazzam, Hitchcock, E. A., Howard, T., Hunicke, Jewett, Judson, Koberle, McCulloch, R., McLure, Maxon, Meier, E. D., Meister, Moore, P. N., Parker, R., Potter, W. B., Reyburn, Rissman, Robertson, J. D., Simpson, J. C., Spencer, Starek, Steedman, Stockett, Tenny, Thacher, A., Torrey, D., Tuttle, A. L., Walsh, Wheeler, H. A., Winslow, Yeatman, Zukoski, C. F., Zukoski, E. L.

MONTANA.

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NEBRASKA.

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NEVADA.

Clements, Barnett. *Hawthorne*, Knapp, S. A, Jr. *Helene*, Cohen. *Sutro*, Nichols, R. *Tuscarora*, Coffin, H. W. *Virginia City*, Fielding.

NEW HAMPSHIRE.

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Church, J. A., Clarke, T. C., Colby, J. L., Cole, E. M., Comstock, W. O., Conant, Cooper, E., Corning, F. G., Corthell, Coxe, E. T., Coxe, M., Crocker, G. A., Crooke, Cullingworth, Davis, F. W., Davis, H. C., Davis, L. K., De Camp, W. S., De Kalb, Delano, W., Jr., Dewey, W. P., Dominick, Dorsey, Dougherty, Douglas, J., Dudley, P. H., Dwight, Eder, Egleston, Ely, E. B., Ely, L. H., Emery, C. E., Faber du Faur, Ferguson, Walton, Fiske, Flagler, Forbes-Leith, Fohr, Francklyn, C. G., Gibson, C. H., Gifford, Gillet, Greene, Haddock, Hadley, F., Jr., Hall, E. J., Jr., Hamilton, Harrison, R. B, Heckscher, Henderson, J. C., Henning, Hewitt, A. S., Hildreth, R. W., Hildreth, W. E., Holbrook, L., Hooker, W. A., Hulick, Hunt, C. W., Hunt, F. F., Hutton, F. R., Ingalls, Janin, H., Johnson, I. G., Kemp, Kerr, T. B., King, C. C., Kirchhoff, Kunhardt, Kunz, Lamborn, Langcloth, Laureau, Leary, Ledoux, Lewis, J. F., Lilienberg, Lombard, Longacre, Lord, W. B., McDowell, F. H., Macdonald, Mahony, Mannesmann, R., Mannesmann, Robert, Marié, Marsh, C. W., Maynard, Mayo, Miller, H. B., Miller, T. S., Moore, L. B., Moses, O. A., Moxham, Munroe, H. S., Murray, G., Nicoll, Norrie, Olcott, E. E., Park, W. E., Parsons, W. B., Peele, Perry, W. A., Pierce, F. M., Pistor, Porter, H. H., Jr., Powel, de V., Pratt, Purbeck, Rand, A. C., Rand, J. R., Randolph, J. C. F., Raunheim, Raymond, R. W., Reno J. W., Rich, J. M., Rickard, R. D., Ricketts, P. de P., Robertson, W. F., Robins, Rolker, Roosevelt, Rossi, Rothwell, R. P., Ruttmann, Schmitz, Schoonmaker, See, Smith, A. P., Smith, W. A., Snow, C. H., Squier, Stanton, J., Stanton, R. B., Stauffer, Struthers, Swain, Taylor, C., Thacher, W. A., Thomas, D. M., Thompson, R. M., Torrey, H. G., Towne, Tratman, Van Slooten, Von Rosenberg, Waller, Ward, W. P., Warren, G. H, Jr., Waterman, Webb, H. W., Wiley, W. H., Williams, D., Williams, J. T., Wills, Wilson. M. O., Wilson, R. T., Jr., Worthington, Wotherspoon, Wyatt, Young, E. L. *Niagara Falls*, Clement, F. H., May. *Ontario*, Parrott. *Pelham Manor*, Van Cortlandt. *Plattsburgh*, Inman, A. L. *Port Jervis*, Lord, R. F. *Poughkeepsie*, Booth, H., Sutcliffe, Tower, J. T. *Port Henry*, Foote, W. T., Jr., Francis, L. W., Presbrey, Tromblee, Witherbee, F. S., Witherbee, T. F., Witherbee, W. C. *Rondout*, Lindsley, J. G. *Rosebank*, Haasis, D. F. *Schenectady*, Blackwell, Booth, E. H. *Spuyten Duyvil*, Douglas, W, Johnson, I. G. *Sterlington*, Knox, Thiry, J. *Syracuse*, Bellinger, H. P., Bradburn, Cogswell, Frazer, F., Holden, E. F., Neill, W. L., Pennock, Smith, J. W. *Tarrytown*, Holbrook, F. N. *Ticonderoga*, Hooper, W. *Tilly Foster*, McKeen. *Troy*, Ball, C. M., Bell, G. A., Burden, J. A., Coutie, Edmunds, Ferry, C., Gilbert, E. G., Kemp, W., McCrery, McLeod, Mason, W. P., Nason, H. B., Sherrerd, J. M., Sherrerd, M. B., Touceda. *Waterford*, Platt, J. C. *West New Brighton*, Davis G. C., Durfee, Humphey, G. S.

NORTH CAROLINA.

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OHIO.

Akron, Pitkin. *Alliance*, Morgan, T. R., Roepper. *Canal Dover*, Croxton. *Canton*, Bulley. *Cincinnati*, Addy, Aldrich, T. H., Blake, C. G., Burke, Doane, Eldridge, G. F., Gaither, Langdon, D. W., Jr., Locke, J. M., Mack, Maxwell, Plummer, Porter, J. B., Whinery. *Cleveland*, Bartol, Brown, A. E., Brown, F., Brown, H. H., Chase, F. D., Cowles, Cremer, Crowell, Cummer, Dickman, Emmerton, Escobar, F., Falding, Frasch, Fuller, W., Grasselli, C., Grasselli, E., Ireland,

Jopling, R. F., Kimball, Langley, Lihme, Mather, S., Mather, W. G., Miller, L. B., Nye, Oglebay, Pechin, E. C., Potter, J. A., Rattle, Roby, Runyon, Sawyer, W. N., Squire, F. B., Stanley, Swasey, Trasch, Treadway. *Columbus*, Coxe, W. E. C., Crafts, Ferguson, V., Lord, N. W., Orton, Sperr, Sawyer, E. T. *Congo*, Ray. *Corning*, Sharp, C. C. *Cuyahoga Falls*, Hollaway. *Fern Bank*, Kebler, E. A. *Hamilton*, Gordon, A., McKinney. *Jackson*, Brown, L. V., Ede. *Leetonia*, Fowler, C. B. *Lowellville*, Bentley. *Mingo Junction*, Bradley, W. H., Dean. *New Straitsville*, Newton. *Niles*, Thomas, J. M. *Oberlin*, Stoughton. *Shawnee*, Opperman. *Steubenville*, Wilson, J. M. *Talmadge*, Sperry, F. L. *Union Furnace*, Lovejoy. *Youngstown*, Ford, E. L., Jones, F. D., McDonald, T., McKeown, Neilson, J., Williams, E. H., Williams, J. L.

OREGON.

Oswego, Miller, G. S., Pomeroy, J. H. *Sumpter*, Rothwell, J. E. *Wolf Creek*, Hampton. *Yaquina City*, Langguth.

PENNSYLVANIA.

Allegheny, Painter, P. *Allentown*, Clymer, E. T., Fisher, J. J., Hartzell, Hunt, J., Ormrod, G., Weaver. *Altoona*, Davis, W. M., Dudley, C. B., Pease. *Ambler*, Luttgen. *Arnot*, Dodson. *Ashland*, Riley, S. M. *Audenried*, Hollenbeck. *Bear Creek*, Lewis, A. *Beech Creek*, Harvey, I. A. *Berwick*, Zehnder. *Bethlehem*, Acker, Colby, A. L., Danziger, DeSaulles, DeSchweinitz, Fritz, Myers, G. H., Schropp, White, M., Williams, E. H., Jr., Wolle. *Birdsboro*, Brooke, G., Harrison, G. W., Wittman. *Braddock*, Clark, E., Dinkey, Gayley, Murray, C. B., Robeson, J. S., Schwab. *Bradford*, Newell, A. W. *Buffington*, Claghorn, C. R. *Burnham*, Kent, R., Stevenson, A. A. *Carlisle*, Long, J. C. *Catasauqua*, Elverson, Hazard, J. C., Peckitt, Scholl, Seaman, H. J., Thomas, J. W., Thomas, S., Williams, O. *Centralia*, Reese, E. *Chambersburg*, Kennedy, J. S. *Chester*, Deemer. *Chickies*, Haldeman. *Clearfield*, Kurtz, H. M. *Columbia*, Connor, B. F., Eckman. *Conshohocken*, Lukens, Wood, H. *Cornwall*, Brady, A., Freeman, W. C., Grittinger, Scott, J. H. *Danville*, McGinnes, Polk. *Drifton*, Coxe, A. B, Jr., Coxe, E. B., Coxe, E. B., Jr., McClellan, Wagner, J. R. *Dunbar*, Lang, W., Long, W. *Duquesne*, Camp, J. M., McDonald, S., Miller, H. B., Upton. *Easton*, Eyerman, Fackenthal, J. S., Firmstone, F., Green, C. B., Hart, E., Jones, C., Knight, F. H., Porter, J. M., Shimer, Silliman, Whitaker. *Eckley*, Coxe, A. B. *Emaus*, Ormrod, J. D. *Erie*, Davenport, C. W., Gresley. *Etna*, Crowther, Kennedy, H. *Everett*, Langdon, N. M. *Ford City*, Robinson, D. S. *Fort Washington*, Hartranft. *Germantown*, Brown, A. P., Lindsay, Pitman. *Girardville*, Wagner, E. C. *Harrisburg*, Bailey, E., Jr., Boyd, J. Y., McCormick, H., McCormick, H., Jr., McCormick, V. C., McCreath, Rader, Rose, W. J. *Hastings*, Fraser. *Hazleton*, Jones, T. D., Markle, A., McNair, Roderick. *Helvetia*, McLeavy. *Hokendauqua*, Thomas, D. H., Thomas, J., Thomas, S. R., Van Wickel. *Hollidaysburg*, McLanahan. *Homestead*, Corey, Eilers, F. *Horatio*, Fisher, T. *Jeansville*, Brooke, H., Haydon, J. C. *Jeddo*, Markle. *Joanna Furnace*, Smith, C. G. *Johnstown*, Fulton, J., Moore, M. G., Morgan, J., Jr., Thackray, Wanner. *Kingston*, Edwards, D., Payne, W. G., Smith, J. B. *Kittanning*, Colwell. *Lancaster*, Grubb. *Latrobe*, Aertsen. *Lebanon*, Amsden, Brock, A., Cullom, Evans, T., Hayes, G. W., Hess, Valentine, S. G., Weimer, A. A., Weimer, J. A. *Leechburg*, Campbell, D. M. *Lewiston*, Lee, R. H., Jr. *Lost Creek*, Brown, D. P., Zerbey. *Meadville*, McClurg. *McKeesport*, Allderdice, Crabtree, Hennin, Hooker, H. M., Tonnelé, Walker, T. B., Wood, T. D. *Mansfield Valley*, Faunce. *Mauch Chunk*, Lentz. *Mechanicsburg*, Longnecker. *Media*, Farnum. *Meyersdale*, Hoblitzell. *Mickleys*, Mickley, E., Mickley, J. J. *Morris Run*, Nearing.

Mount Carmel, Davis, M., Jr. *Munhall*, Berg, Davis, H. J., McConnell, Unger, Wood, E. F. *New Bethlehem*, Sheafer, S. T. *New Castle*, Crawford, J. L., Darley, Johnson, C. H., Kurtz, E. L., Stevenson, J. Jr. *New Kensington*, Hopke. *Norristown*, Humbert, G. J., Newbold, McHose, Slingluff. *Oliver's Mills*, Oliver, P. A. *Olyphant*, Jones, E. *Osceola Mills*, Good. *Parnassus*, Parkin. *Parryville*, Hall, H. K. *Patton*, Brown, E. C. *Pencoyd*, Allen, A. W., Talbot, B. *Philadelphia*, Anderson, G. E., Barns, Barringer, Biddle, Birkinbine, Blair, A. A., Boericke, Bonzano, Borda, Burnham, Casterline, Chance, Chauvenet, S. H., Claghorn, J. R., Clark, C. M., Cofrode, Converse, Cox, J., Jr., Crane, Crozer, Dewees, D'Invilliers, Disston, H. C., Disston, T. S., Dodge, J. M., Donaldson, Dougherty, T. H., Drayton, Drinker, Earnshaw, A., Earnshaw, E. H., Ely, T. N., Field, R. P., Flagg, Frazer, Dr. P., Frazer, R., Garrison, Gatzmer, Gordon, F. W., Graham, T. H., Griscom, Haines, Harden, E. B., Hartman, Hastings, Hawkins, E., Heckscher, Hill., F. A., Hinchman, Hobson, T., Hoffman, J. W., Howe, F. P., Humphrey, A. C., Ingham, James, W. M., Jones, J. F., Jones, W., Keeley, F. J., Keeley, J., King, T. M., Landis, E. K., Lee, R. H., Lehman, A. E., Lehman, G. M., Leisenring, Lennig, Leonard, Lesley, Lyle, Lyman, B. S., McCallum, Maas, Meigs, Miller, A. A., Mitchell, R., Moore, J., Morris, G. C., Morris, H. G., Morris, I. W., Morris, W. H., Myers, H. K., Neilson, W. G., Penrose, R. A. F., Jr., Peters, R., Jr., Pilling, Platt, F., Potts, F. L., Potts, H., Prevost, Pullman, Rand, T. D., Reeves, D., Riley, L. A., Roberts, F. C., Roberts, P., Roberts, P., Jr., Salom, Sanders, R. H., Schaeffer, Dr. C., Sellers, W., Smith, A. D. W., Smith, E. F., Stein, Strobel, Tower, C., Jr., Townsend, D., Townsend, H. T., Webster, W. R., Wheeler, S. B., Wilson, J. A., Wilson, J. R., Wister, J., Wister, F., Wood, W. *Phœnixville*, Brown, W., Hall, J., Harden. *Pine Iron Works*, Bailey. *Pittsburgh*, Amsler, Bakewell, Barnes, P., Best, Blair, T. S., Byers, Chalfant, Church, A. K., Clapp, G. H., Coffin, W. C, Collins, H. E., Curry, H. M., Curtis, Darlington, Darsie, Doxrud, DuPuy, Eastwick, Ferguson, E. M., Ferris, G. W. G., Jr., Fitzhugh, C. L., Ford, S. A., French, Frick, H. C., Fricke, F. G., Gamble, Giles, Gillespie, Hall, C. M., Hillard, Hemphill, Hoffstot, Hughes, T. E., Hunsiker, Hunt, A. E., Jones, B. F., Jones, W. L., Kennedy, J., Lash, Lauder, McCandless, Martin, R. L., Metcalf, O., Metcalf, W., Mitchell, W. K., Munroe, R., Jr., Myers, G. F., Nimick, Oliver, H. W., Jr., Page, G. S., Painter, A. E. W., Park, W. G., Phipps, Pitcairn, Porter, H. K., Porter, J. C., Rea, Ricketson, Salsbury, Scaife, C. C., Scaife, O. P., Scaife, W. L., Schaeffer, C. F., Schellenberg, Schwartz, Scott, J., Scott, R. J., Singer, G., Singer, R. R., Singer, W. H., Speer, Stafford, Stutz, Swindell, Tyson, J. W., Jr., Veeder, Walker, R. L., Weeks, Wells, Westinghouse, Wilcox, Williams, F., Wilkins, W. G., Wood, W. D. *Pittston*, Law. *Pleasantville*, Carll. *Port Carbon*, Allison, R. *Port Kennedy*, Wilkins, W. *Pottstown*, Cook, E. S., Evans, H., Fegely, Hammer, H., Hilles, Janney, Lessig, Morris, R. J., Potts, G. H., Rice, J., Roe, Saylor, Sotter, Steele, Thompson, F. E., Weimer, J. P. *Pottsville*, Atkins, Carter, F., Cooper, H. P., Luther, Sheafer, A. W., Sheafer, W. L., Thompson, H. S., Werther. *Punxsutawney*, Cunningham, J. S. *Reading*, Baer, Boyer, J. L., Boyer, W. M., Broden, Carpenter, J. H., Froment, Leaf, McIlvain, W. R., Quier, E. A., Quier, L., Smink. *Ridgway*, Ravenscroft, Robertson, D. *Riegelsville*, Clymer, L. S., Fackenthal, B. F., Jr. *Robesonia*, Taylor, G. R., *Rockhill Furnace*, Sims, A. W. *Sandy Run*, Leisenring, W. *Scottdale*, Kennedy, O. W. *Scranton*, Archbald, J., Archbald, J., Jr., Barnard, Belin, Boies, Brooks, R. G., Connell, W., Dale, Finch, Foster, R. J., Hines, Hosie, Hughes, B., Jermyn, Johnson, O. S., Lawrence, W. L., Lee, A. H., Mattes, C. C., Parke, Platt, F. E., Richmond, Scharar, Scranton, W. W., Sherrerd, A. H., Simpson, C. D., Simpson, H. P., Smith, W. T., Snyder, Taylor, W. H., Vandling, Wolf, T. G.

Shamokin, Williams, M. *Sharon*, Buhl, Eagan, McClure, S., Wheeler, E. A. *Sharpsburg*, Koch. *Sharpsville*, Barrows, Pierce, J. B., Trautvetter. *Sheridan*, Kaufman, W. M. *South Bethlehem*, Coleman, C. P., Convers, Davenport, R. W., Frazier, B. W., Jaques, Linderman, Manley, McIlvaine, E. M., Sohon, Wilbur, R. H., Wilbur, W. A. *St. Davids*, Phillips, T. H. *State College*, Stoek. *Steelton*, Armstrong, E., Campbell, H. H., Dougherty, J. W., Felton, Gross, King, C. F., Martin. J. B. *Stowe*, Hartshorne. *Swedeland*, Lychenheim. *Swissdale*, Hopkins. *Thurlow*, Babbitt, Bell, J. M., Cockburn, Houston, C. B., Wellman, C. H., Wellman, R. B. *Upland*, Wellman, S. T., Weston. *Uniontown*, Boyd, J. D., Connor, C., Keighley. *Wellsboro*, Hardt. *White Mills*, Dorflinger. *Wilkes-Barre*, Bowden, Conyngham, C. M., Conyngham, J. N., Lathrop, W. A., Lawall, Moister, Norris, R. Van A., Reets, Richards, W. J., Stearns, I. A., Warriner. *Wilkinsburg*, Bailey, C., Grammer, Kerr, D. G., Thomson, F. du P. *Winton*, Connor, E. T. *Wyebrook*, Potts, W. M. *Wyncote*, Pardee, A., Jr.

RHODE ISLAND.

Central Falls, Miller, C. H. *Newport*, Emmons, A. B. *Peace Dale*, Hazard, R.

SOUTH CAROLINA.

Charleston, Chazal. *Haile Gold Mine, P. O.*, Thies.

SOUTH DAKOTA.

Central City, Blackstone. *Deadwood*, Anderson, R. G., Carpenter, F. R., Kuntzen. Thompson, S. R. *Hill City*, Baldwin, J. M. *Keystone*, Simmons. *Lead City*, Grier. *Rapid City*, Headden, Jenney, Willsie. *Terraville*, Skinner.

TENNESSEE.

Blue Spring, Waters, A. L. *Chattanooga*, Chamberlain, Colyar, Finley. *Clarksville*, Gracey, Woodward, H. G. *Cumberland Gap*, Lawton, J. E. *Dayton*, Jamme. *Ducktown*, Henrich. *Elizabethton*, Dalgleisch. *Embreville*, Love. *Harriman*, Bryant, L. E. *Hartranft*, Jardine, Welsh. *Knoxville*, Howell. B. P., Payne, J. K. Wait. *Nashville*, Bowron, J., Dudley, W. L., Magruder. *Pikeville*, Ormsbee, Perin. *Rockwood*, Warner. *Sewanee*, Quintard. *South Pittsburg*, Bowron, W. M., Lodge, J. *Tracy City*, Bowron, C. E., Shook. *Warner*, Gaines.

TEXAS.

Austin, Dumble, Kennedy, W. *Eagle Pass*, Tuttle, E. G. *El Paso*, Claypool, Goodrich, Groesbeck, Rose, W. W. *San Antonio*, Alexander, A. A., Alexander, J. S., Orynski. *Shafter*, Noyes.

UTAH.

Bingham, Humphrey, C. *Castle Gate*, Sharp, W. G. *Mammoth*, Robinson, G. H. *Ophir*, Wall. *Park City*, Blood, Moffat, Russell, E. H. *Salt Lake City*, Axford, Chambers, R. C., Colbath, Daggett, Dickert, Hill, H. C., Holden, L. E., Karrick, Kingsbury, Lavagnino, Morse, P. S., Neill, J. W., Palmer, O. A., Snow, G. W., Terhune, Trent, Treweek, Walker, J. R., Weir, Wilson, W. A. *Sandy*, Norton, L. H.

VERMONT.

Fairlee, Long, W. H. *St. Johnsbury*, Paddock.

VIRGINIA.

Abingdon, Bache. *Baker Mines*, McKee. *Big Stone Gap*, Fox, Hodge, J. M. *Buena Vista*, Richards, F. B. *Buchanan*, Jolliffe. *Craig City*, Connell, W. A. *Elkhorn*, Harris, G. W. *Graham*, Graham, W. *Harrisonburg*, Allen, R. B. *Iron Gate*, Jones, T. C. *Lexington*, Corse. *Longdale*, Firmstone, H., Johnson, G. R., Johnson, J. E. *Low Moor*, Merry. *Max Meadows*, Maury. *Norfolk*, Graham, J., Jr., Lamb, Riddle. *Norton*, Allen, J. H. *Pulaski*, Duane, Jones, T. J., Patterson, R. P. *Richmond*, Blankenship, Froehling. *Roanoke*, Bachman, D. I., Bartlett, J. H., Coe, Davis, W. W, Jr., Fackenthal, M., Soule, Wallis. *Shenandoah*, Sims, H. N. *Staunton*, Hotchkiss. *Triford*, Dunlap. *Warrenton*, Britton. *Wytheville*, Boyd, C. R.

WASHINGTON.

Anacortes, Bowman. *Ellensburgh*, Hubbell. *Seattle*, Hainesworth, Ross. *Spokane*, Carrel. *Tacoma*, Bretherton, W. L., Lang, H.

WEST VIRGINIA.

Ansted, Page, W. N. *Coketon*, Ramsay, G. S. *Concho*, Harris, W. J. *Coopers*, Keatley. *Eckman*, Morris, S. F. *Elkhorn*, Houston, T. E., Tierney, J. J., Tierney, L. E., Wilson, E. B. *Elkins*, Davis, H. E. *Glen Jean*, McKill. *Landgraff*, Ord. *Maybeury*, Buck, S. M., Hutchinson, E. S. *Parkersburg*, Gardner, G. Clinton. *Rush Run*, Howald. *Shaw*, Lidner. *Thurmond*, Atkinson. *Vivian*, Patterson, G. S. *Wheeling*, Arnberg, Hearne, Rawlings, Wiles.

WISCONSIN.

Ashland, Dunham, Hunt, M. R. *Commonwealth*, Davidson, O. C. *Iron Belt*, McVichie. *Milwaukee*, Barr, Bean, Conro, Goetz, Hinton, Hulst, Schlesinger, Smith, H. E. *Oshkosh*, Gile. *Richland Center*, Smith, F. C. *Spring Valley*, Eagle. *West Superior*, Oberholser, Robertson, K.

WYOMING.

Rawlins, Ricketts, L. D.

CANADA.

Black Lake, P. Q., Penhale. *Capelton*, Blue, J. *Golden, B. C.*, Fowler, S. S. *Kingston, Ont.*, Spotswood. *Marmora, Ont.*, Woodworth. *Montreal*, Drummond, G. E., Drummond, T. J., Granger, Harrington, McDougall, Molson, Torrance. *Ottawa, Ont.*, Bell, R., Ingall, Macfarlane, T., Small, H. B. *Quesnelle Forks*, Hobson, J. R. *Radnor Forges*, Drummond. *Rat Portage*, Payne, A. C. *Sherbrooke*, Bennetts, Buck, T. P., Halsey, F. A. *St. John*, Markham. *Toronto*, Blue, A., Ledyard, Merritt, Mills, S. D.

NEWFOUNDLAND.

St. Johns, Burchell, H. C.

NOVA SCOTIA.

Bedford Station, Christie. *Bridgeville*, Sjöstedt. *Caledonia Mines*, Revere. *Country Harbor Mines*, McDonald, J. C. *Eureka*, Chambers, R. E. *Gowrie Mines*, Archibald. *Halifax*, Allison, E. P., Gue, Willis, C. E. *Isaac's Harbor*, Andrews. *Londonderry*, Leckie, R. G. *Montague*, Thomas, W. R. *Musquodoboit Harbor*, Reid, J. M. *Oldham Gold Mines*, Hardman. *New Glasgow*, Matheson. *Sydney*, McLennan. *Stellarton*, Poole. *Torbrook Mines*, Leckie, R. G. E. *Truro*, Mason, F. H., Stuart, G. W. *Waverly*, Macduff, Wilson, B. C. *Westville*, Fergie. *Whitebu n Mines*, Partington. *Windsor*, Dimock.

MEXICO.

Chihuahua, Brodie, Davis, B., Hendey, Hofmann, O., Reinhardt. *Coahuila*, Garthwaite, Howe, E. *Durango*, Büttner, Oldoerp, Schlemm, Viggers, W. *El Oro*, Blake, F. H. *Jalisco*, Young, J. W. R. *Huantla*, Watson, B. C. *Mazatlan*, Gosset. *Mexico*, Braschi, Castillo, Chism, Feustman. *Michoacan*, Davey, G. *Monterey*, Austin, T. S., Schneider, A. F., Wilson, N. R. *Pachuca*, Bawden, Blasquez, Fairchild, Malcolmson, Pritchett, Pullon. *San Luis Potosi*, Coghlan, Hazelton, Taylor, F. W. *Sonora*, Bonillas, Leete. *Tampico*, Pani. *Zacatecas*, Bohn, Emmons, N. H., Huchinson, R. B., Wood, J. G.

CENTRAL AMERICA.

Costa Rica, Dufourcq. *Honduras*, Clark, W. P., Kingsley.

CUBA.

Matanzas, Polledo.

SOUTH AMERICA.

Argentine Republic, MacGinniss. *Brazil*, Chalmers. *British Guiana*, Winter. *Chili, Santiago*, San Roman. *Colombia*, Carlton, Enstice, Green, J. G., Kerr, M. B., LeFevre, H. F., Nichols, N. J., Russell, A. J. *Ecuador*, Pinder. *Peru, Caylloma*, Francis, W. R. *Lima*, Elguera, Figari, Gildemeister, Letts, Johnston, J. H., Watson, F. M.

ENGLAND.

Acton, Daw. *Belchworth*, Davidson, W. B. M. *Bremgarten*, Woodhouse. *Chelston*, Clemes. *Cornwall*, Hodge, A., Louis, H., Richards, J. T., Rowe, Seccombe, A. *Darwen*, Holgate. *Dovercourt*, Charleton. *Dudley*, Hughes, H. W. *Kent*, Power, F. D. *Leeds*, Dalton. *Liverpool*, Frossard, Pearson, J. E. *London*, Allen, J. F., Attwood, Bayliss, Bennet, Berdell, Chester, E. D., Claudet, Davis, L. M., De Crano, Delmar, Duffield, Fowler, P., Francis, G. G., Frecheville, R. J., Gilchrist, Hoefer, E., Hughes, A. D., Lawrence, H. L., Louis, D., McDermott, Merricks, Pearsall, Pearse, A. L., Perkins, H. C., Rickard, T., Sandberg, Scott, F. B., Seymore, Smith, H., Jr., Taylor, P., Touzeau, Vautin, Varden, Webster, J., Western, Whitmore, Williams, H. J. C., Wilkinson, W. F., Wilson, J. W., Woakes. *Middlesborough*, Bell, L. *Redhill*, Frecheville, W. *Sheffield*, Hadfield, Hardwick, Stubbs, F. *Tavistock*, Richards. *Totnes*, Chenhall. *West Hartlepool*, Thomlinson. *Worcester*, Hooper, E. *Yorkshire*, Richards, E. W.

SCOTLAND.

Glasgow, Crookston, Feldtman, MacArthur. Pollok, Riley, J.

WALES.

Aberdare, Lewis, W. T. *Cardiff*, Brown, T. F. *Glamorgan*, Martin, E. P. *Llandudno*, Foster, C. Le Neve.

AUSTRIA.

Leoben, Hoefer, H., v. Tunner. *Vienna*, Posepny. *Zalathna*, Hollow, J. T.

BELGIUM.

Seraing, DeDeken.

FRANCE.

Paris, Arnaud, Bel, Chaper, Collin, Daleas, Daubrée, Delrez, Duchanoy, Ellicott, H. T., Haton de la Goupilliere, Heard, Jousselin, Knoertzer, Levat, Osmond, Schneider, P., Würgler. *Seine et Oise*, Valton, F.

GERMANY.

Altenessen, Krabler. *Apolda*, Hahn, O. H. *Baden*, Jabs, Meier, J. W. *Berlin*, Hahn, G., Kerl, Serlo, Wedding, Wolff. *Dortmund*, Brauns. *Düsseldorf*, Daelen, Schroedter. *Freiberg*, Gaetschmann, Richter, Waller, G. A. *Metz*, Sorge. *Ruhrort*, Thielen. *Siegen*, Macco. *Wiesbaden*, Massenez.

ITALY.

Florence, Capacci.

RUSSIA.

Orenburg, Zellenkoff.

SPAIN.

Cordova, Delprat. *Provincia de Huelva*, Carr, Rich, W., Waugh. *Provincia de Jaen*, Power, I. M., Tonkin. *Province of Seville*, Maurice.

SWEDEN.

Falun, von Steyern. *Filipstad*, Odelstjerna. *Motala*, Angström. *Stockholm*, Åkerman, Lundbohm, Setterwall. *Upsala*, Sjögren.

TURKEY.

Constantinople, Bunning. *Smyrna*, Manzavino.

INDIA.

Bombay, Reynolds. *Calcutta*, Doyle. *Mysore*, Marsh, W. *Singapore*, McKillop.

JAPAN.

Chikugo, Dan. *Chikuzen*, Adachi. *Hokkaido*, Kawai. *Osaka*, Kuwabara. *Shimaneken*, Tsuno. *Tokio*, Kanda, Kasahara, Kitsunesaki, Kondo, Uchida. *Uagi*, Yamada. *Yamaguchiken*, Kada.

SOUTH AFRICA.

Cape Colony, Kimberley, Robeson, A. M., Williams, G. F. *Namaqualand*, Faragher. *Natal, Pietermaritzburg*, Denny. *Transvaal, Barberton*, Phillips, A. G. *Johannesburg*, Berry, J. F., Button, Butters, Clement, V. M., Eissler, Farrar, Furlonge, Grey, Hancock, Inman, Jennings, H., Jessop, Miller, H. W., Morris, H., Rathbone, Webster, H. L., Wiltsee. *Pietersburg*, Halder. *Swaziland*, Metcalf, A. T.

AUSTRALIA.

New South Wales, Broken Hill, Adams, R., Ashcroft, Cleland, Horwood, Howell, J., Koehler, McKinnon, Pearson, J. F., Poage, Roberts, G. M., Savage, Shephard, Smith, G., Sutherland, J. F., Wilson, Harry. *Lucknow*, Irwin. *Nundle*, Chrichton. *Sidney*, Atherton, T. W. T., Bensusan, Drake, F. M., Dunstan, Helms, Mackenzie, Storer. *Silverton*, Dudley, U. *Queensland, Stanthorpe*, Beaumont. *South Australia, Adelaide*, East, Fulton, G. E., Hawker, Higgin, Macandrew. *Blinman*, Rosewarne. *Gawler*, Martin, J. F. *North Adelaide*, Higgins, Trewenach. *Victoria, Ballarat*, Lidgey, Payne, E. *Harrietville*, Davey, T. G. *Melbourne*, Brown, A. T., Chapman, Collins, W. J., Hartrick, Odling, Saddler, Walcott, R. H. *Western Australia, Coolgardie*, Corbould, W. H., Gibson, R. *Perth*, Backhouse, F. H.

NEW ZEALAND.

Bendigo, Hosking. *Dunedin*, Allen, Jas., Larnach, Ulrich. *Otago*, Jackson, *Wellington*, Gordon, H. A., Seddon, R. J. *W. Greymouth*, Bishop. *Westport*. Proust.

TASMANIA

Emu Bay, Provis, J. *Hobart*, Williams, L. *West Coast*, Browne, A. R , Provis, R. *Zeehan*, Beardsley, Thomae.

[illegible]ICERS.

D'Invilliers, E. V.,																								V
Drinker, Henry S.,							M	M	M															
Drown, Thomas M.,		M	S	S	S	S	S	S	S	S	S	S	S									V	V	
Dudley, Charles B.,										V	V													
Egleston, Thomas,	M	V	V	V			V	V						V	V		P							
Eilers, Anton,					M	M	M					M	M	M										
Ely, T. N.,												V	V											
Emmons, S. F.,													V	V						V	V			
Fackenthal, B. F., Jr.																	M	M	M					
Firmstone, Frank,			M		V	V								M	M	M			M	M	M			
Forsyth, Robert,																		M	M	M				
Frazer, Persifor,										V	V													
Frazier, B. W.,				M	M	M		M	M	M														
Fritz, John,					V																			P
Fulton, John,															V	V								
Gaujot, E.,	M	M																						
Goetz, Geo. W.,																						M	M	M
Heinrich, Oswald J.,					M	M	M																	
Hewitt, Abram S.,		M	M	M	M	P														P				
Hofman, H. O.,																								M
Holley, A. L.,				V	P		M	M	M															
Hollis, H. L.,																						M	M	M
Holloway, J. F.,																	V	V						V
Howe, H. M.,									V	V						M	M	M		V	V		P	
Hunt, A. E.,													P					V	V					

[illegible]

Shinn, William P.,							V	V		P														
Shook, A. M.,																							M	M
Smock, John C.,					M	M	M														M	M	M	
Spilsbury, E. G.,															M	M	M						V	V
Stanton John,																						V	V	
Stetefeldt, C. A.,															V	V								
Swoyer, J. H.,	V																							
Symons, W. R.,	V	V	M	M																				
Taylor, W. J.,																				M	M	M		
Thurston, Robert H.,								V	V															
Thomas, David,	P																							
Thomas, Samuel,									V	V														
Thompson, Charles O.											V	V												
Weeks, J. D.,																V	V			M	M	M		
Wellman, S. T.,													V	V						M	M	M		
Williams, T. M.,	M																							
Williamson, J. Pryor,	T	T																						
Witherbee, Thos. F.,						M	M	M																

LIST OF THE MEETINGS OF THE INSTITUTE AND THEIR LOCALITIES FROM ITS ORGANIZATION TO FEBRUARY, 1894.

Number.	Place.	Date.	Transactions.
I.	Wilkes-Barre, Pa.,*	May, 1871,	i. 3
II.	Bethlehem, Pa.,	August, 1871,	i. 10
III.	Troy, N. Y.,	November, 1871,	i. 13
IV.	Philadelphia, Pa.,	February, 1872,	i. 17
V.	New York, N. Y.,*	May, 1872,	i. 20
VI.	Pittsburgh, Pa.,	October, 1872,	i. 25
VII.	Boston, Mass.,	February, 1873,	i. 28
VIII.	Philadelphia, Pa.,*	May, 1873,	ii. 3
IX.	Easton, Pa.,	October, 1873,	ii. 7
X.	New York, N. Y.,	February, 1874,	ii. 11
XI.	St. Louis, Mo.,*	May, 1874,	iii. 3
XII.	Hazleton, Pa.,	October, 1874,	iii. 8
XIII.	New Haven, Conn.,	February, 1875,	iii. 15
XIV.	Dover, N. J.,*	May, 1875,	iv. 3
XV.	Cleveland, O.,	October, 1875,	iv. 9
XVI.	Washington, D. C.,	February, 1876,	iv. 18
XVII.	Philadelphia, Pa.,†	June, 1876,	v. 3
XVIII.	Philadelphia, Pa.,	October, 1876,	v. 19
XIX.	New York, N. Y.,	February, 1877,	v. 27
XX.	Wilkes-Barre, Pa.,*	May, 1877,	vi. 3
XXI.	Amenia, N. Y.,	October, 1877,	vi. 10
XXII.	Philadelphia, Pa.,	February, 1878,	vi. 18
XXIII.	Chattanooga, Tenn.,*	May, 1878,	vii. 3
XXIV.	Lake George, N. Y.,	October, 1878,	vii. 103
XXV.	Baltimore, Md.,*	February, 1879,	vii. 217
XXVI.	Pittsburgh, Pa.,	May, 1879,	viii. 3
XXVII.	Montreal, Canada,	September, 1879,	viii. 121
XXVIII.	New York, N. Y.,*	February, 1880,	viii. 275
XXIX.	Lake Superior, Mich.,	August, 1880,	ix. 1
XXX.	Philadelphia, Pa.,*	February, 1881,	ix. 275
XXXI.	Staunton, Va.,	May, 1881,	x. 1
XXXII.	Harrisburg, Pa.,	October, 1881,	x. 119
XXXIII.	Washington, D. C.,*	February, 1882,	x. 225
XXXIV.	Denver, Col.,	August, 1882,	xi. 1
XXXV.	Boston, Mass.,*	February, 1883,	xi. 217
XXXVI.	Roanoke, Va.,	June, 1883,	xii. 3
XXXVII.	Troy, N. Y.,	October, 1883,	xii. 175
XXXVIII.	Cincinnati, O.,*	February, 1884,	xii. 447
XXXIX.	Chicago, Ill.,	May, 1884,	xiii. 1
XL.	Philadelphia, Pa.,	September, 1884,	xiii. 285
XLI.	New York, N. Y.,*	February, 1885,	xiii. 585

* Annual meeting for the election of officers. The rules were amended at the Chattanooga meeting, May, 1878, changing the annual election from May to February.

† Begun in May at Easton, Pa., for the election of officers, and adjourned to Philadelphia.

Number.	Place.	Date.	Transactions.
XLII.	Chattanooga, Tenn.,	May, 1885,	xiv. 1
XLIII.	Halifax, N. S.,	September, 1885,	xiv. 307
XLIV.	Pittsburgh, Pa.,*	February, 1886,	xiv. 587
XLV.	Bethlehem, Pa.,	May, 1886,	xv. lxiii.
XLVI.	St. Louis, Mo.,	October, 1886,	xv. lxx.
XLVII.	Scranton, Pa.*	February, 1887,	xv. lxxvii.
XLVIII.	Utah and Montana,	July, 1887,	xvi. xvii.
XLIX.	Duluth, Minn.,	July, 1887,	xvi. xxiv.
L.	Boston, Mass.,*	February, 1888,	xvi. xxviii.
LI.	Birmingham, Ala.,	May, 1888,	xvii. xix.
LII.	Buffalo, N. Y.,	October, 1888,	xvii. xxiv.
LIII.	New York, N. Y.,*	February, 1889,	xvii. xxxi.
LIV.	Colorado,	June, 1889,	xviii. xvii.
LV.	Ottawa, Canada,	October, 1889,	xviii. xxiv.
LVI.	Washington, D. C.,*	February, 1890,	xviii. xxx.
LVII.	New York, N. Y.,	September, 1890,	xix. vii.
LVIII.	New York, N. Y.*	February, 1891,	xix. xxv.
LIX.	Cleveland, O.,	June, 1891,	xx. xvi.
LX.	Glen Summit, Pa.,	October, 1891,	xx. lxi.
LXI.	Baltimore, Md.,*	February, 1892,	xxi. xix.
LXII.	Plattsburgh, N. Y.,	June, 1892,	xxi. xxxiii.
LXIII.	Reading, Pa.,	October, 1892,	xxi. xliv.
LXIV.	Montreal, Canada,*	February, 1893,	xxi. lii.
LXV.	Chicago, Ill.	August, 1893,	xxii. xiii.
LXVI.	Virginia Beach, Va.,*	February, 1894,	xxiv.

* Annual meeting for the election of officers.

PUBLICATIONS.

THE publications of the Institute comprise:

1. The minutes of the Proceedings of each Meeting, published in pamphlet form.

2. Such of the papers presented or read by title at each Meeting as are furnished by the authors and approved by the Council for full publication. (In nearly all cases in which papers, the titles of which appear in the Proceedings, are not subsequently published, they have been withdrawn by the authors.) These papers are published separately in pamphlet form, and are marked "Subject to Revision." A small supply, beyond the edition distributed, is retained to meet subsequent demand. There are no copies on hand of papers read before 1880. The stock is nearly complete from 1880.

3. Annual volumes of *Transactions*, containing the list of officers, rules, etc.; the Proceedings; and the papers, *revised for final publication*. (In this revision after the preliminary publication, authors are permitted to use the largest liberty; and the changes and additions made in papers are sometimes important. It should be borne in mind, by those who study or quote a paper in the preliminary edition, that they may not have in that form the ultimate and deliberate expression of the author's views. It should be added, however, that in the majority of cases there is no essential change, the correction of typographical errors and additions of later information being the usual alterations.)

4. Special editions of separate papers, for which there is demand. These are fully revised, and are usually issued in pamphlet covers.

5. Books. Under this head the only publications are an Index to Vols. I. to XV. inclusive; an Index to Vols. XVI. to XX. inclusive; a Glossary of Mining and Metallurgical Terms; and a Memorial of Alexander Lyman Holley.

All the foregoing publications are sent free to members and associates *not in arrears at the time of publication*. They are also for sale at the office of the Secretary, or are sent to purchasers by mail or express, charges paid, on receipt of the price by the Secretary, as follows:

Classes 1 and 2, above mentioned, at the following rates:

No. of Pages.	Single Copies.	10 Copies.	20 Copies.
8 or less	$0 06	$0 30	$0 50
8 to 12 inclusive	0 08	0 60	1 00
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20 to 24 "	0 20	1 50	2 50
Over 24 "	0 20	1 75	3 00

The following papers contained in Vols. XXII. and XXIII. are for sale at special rates: "Genesis of Ore-Deposits," by Prof. Franz Posepny, price $1; "Microscopic Metallography," by F. Osmond, price 30 cents; "Micro-Structure of Ingot-Iron in Cast Ingots," by Prof. A. Martens, price 50 cents; "Micro-Structure of Steel," by Albert Sauveur, price 30 cents; "The Open-Hearth Process," by H. H. Campbell, price $1; "Iron Alloys with Special Reference to Manganese Steel," by R. A. Hadfield, price 30 cents.

Class 3. This class now comprises twenty-three volumes of *Transactions*, for sale as follows: Vols. I. to IV., inclusive, at $2 each; Vols. V. to VIII., inclusive, at $3 each; all other volumes at $5 each, except Vol. X., of which the supply on hand is smallest, and the price of which is $10. These prices are for paper covers. Half-morocco binding, $1 extra per volume.

Class 4. This class now includes "Steel Rails" (Papers by Messrs. Sandberg, Dudley and Holley, and discussions at two meetings in 1881, from Vol. IX. of the *Transactions*), price $1; "Technical Education" (Papers and discussions at the XVIIth [Philadelphia] meeting, in 1876 —mostly not in the *Transactions*), price 50 cents. "List of Members, Rules, etc.," price 25 cents.

Class 5. Index to Vols. I. to XV., inclusive, of the *Transactions*, price, in stiff cloth covers, $1, in half-morocco, $2. Index to Vols. XVI. to XX. inclusive, price in paper covers, $1. Indexes I.–XV. and XVI.–XX. bound together in one volume, cloth, $2.50. "Memorial of Alexander Lyman Holley," in cloth, with frontispiece-portrait, price $1. "Glossary of Mining and Metallurgical Terms," by R. W. Raymond (from Vol. IX. of the *Transactions*), in cloth, price 50 cents. "The Genesis of Ore-Deposits" (paper of Prof. Franz Posepny, with Discussions), price in cloth, $2.

AUTHORS' EDITIONS.

Extra copies, when ordered before the types have been distributed, are furnished to authors under Rule VII., at the following rates:

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20 to 24 "	3 75	5 25	7 25	1 75
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When a paper contains one or more *separate* plates or "folders," these will be charged in reprinting as follows: One page or one fold, the same as four pages in the above table; each additional fold, the same as four additional pages. These prices are for plates on the ordinary paper, used in the edition issued "subject to revision." If special bank-note paper is desired, such as is used in the Volumes of *Transactions*, the price for the plates will be doubled.

All communications and remittances should be addressed to R. W. Raymond, Secretary, P. O. Box 223, New York City.

RULES

ADOPTED MAY, 1873. AMENDED MAY, 1875, 1877, AND 1878, FEBRUARY, 1880, 1881, 1887, AND 1890.

I.

OBJECTS.

THE objects of the AMERICAN INSTITUTE OF MINING ENGINEERS are to promote the arts and sciences connected with the economical production of the useful minerals and metals, and the welfare of those employed in these industries, by means of meetings for social intercourse, and the reading and discussion of professional papers, and to circulate, by means of publications among its members and associates, the information thus obtained.

II.

MEMBERSHIP.

The Institute shall consist of Members, Honorary Members, and Associates. Members and Honorary Members shall be professional mining engineers, geologists, metallurgists, or chemists, or persons practically engaged in mining, metallurgy, or metallurgical engineering. Associates shall include all suitable persons desirous of being connected with the Institute, and duly elected as hereinafter provided. Each person desirous of becoming a member or associate shall be proposed by at least three members or associates, approved by the Council, and elected by ballot at a regular meeting (or by ballot at any time conducted through the mail, as the Council may prescribe) upon receiving three-fourths of the votes cast, and shall become a member or associate on the payment of his first dues. Each person proposed as an honorary member shall be recommended by at least ten members or associates, approved by the Council, and elected by ballot at a regular meeting (or by ballot at any time conducted through the mail, as the Council may prescribe) on receiving nine-tenths of the votes cast; *Provided*, that the number of honorary members shall not exceed twenty. The Council may at any time change the classification of a person elected as associate, so as to make him a member, or *vice versa*, subject to the approval of the Institute. All members and associates shall be equally entitled to the privileges of membership; *Provided*, that honorary members shall not be entitled to vote.

Any member or associate may be stricken from the list on recommendation of the Council, by the vote of three-fourths of the members and associates present at any annual meeting, due notice having been mailed in writing by the Secretary to the said member or associate.

III.

DUES.

The dues of members and associates shall be ten dollars, payable upon their election, and ten dollars per annum thereafter, payable in advance at the annual meeting. Honorary members shall not be liable to dues. Any member or associate not in arrears may become by the payment of one hundred dollars at one time a life-member or associate, and shall not be liable thereafter to annual dues. Any member or associate in arrears may, at the discretion of the Council, be deprived of the receipt of publications, or stricken from the list of members when in arrears for one year; *Provided*, that he may be restored to membership by the Council on payment of all arrears, or by re-election after an interval of three years.

IV.

OFFICERS.

The affairs of the Institute shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers, a Secretary and a Treasurer, who shall be elected from among the members and associates of the Institute at the annual meetings, to hold office as follows:

The President, the Secretary, and the Treasurer for one year (and no person shall be eligible for immediate re-election as President who shall have held that office subsequent to the adoption of these rules, for two consecutive years), the Vice-Presidents for two years, and the Managers for three years; and no Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected. At each annual meeting a President, three Vice-Presidents, three Managers, a Secretary and a Treasurer shall be elected, and the term of office shall continue until the adjournment of the meeting at which their successors are elected.

The duties of all officers shall be such as usually pertain to their offices, or may be delegated to them by the Council or the Institute; and the Council may in its discretion require bonds to be given by the Treasurer. At each annual meeting the Council shall make a report of proceedings to the Institute, together with a financial statement.

Vacancies in the Council may occur by death or resignation; or the Council may, by a vote of the majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings or perform the duties of his office. All vacancies shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *Provided*, that the said appointment shall not render him ineligible at the next annual meeting.

Five members of the Council shall constitute a quorum; but the Council may appoint an Executive Committee, or business may be transacted at a regularly called meeting of the Council, at which less than a quorum is present, subject to the approval of a majority of the Council, subsequently given in writing to the Secretary and recorded by him with the minutes.

V.

ELECTIONS.

The annual election shall be conducted as follows: Nominations may be sent in writing to the Secretary, accompanied with the names of the proposers, at any time *not* less than thirty days before the annual meeting; and the Secretary shall, not less than two weeks before the said meeting, mail to every member or associate (except honorary members), a list of all the nominations for each office so received, together with a copy of this rule, and the names of the persons ineligible for election to each office; and if the Council, or a Committee thereof, appointed for the purpose, shall have recommended any nominations, such recommendation may also be sent to members and associates with the said list of all nominations *made*, but not upon the same paper. And each member or associate, qualified to vote, may vote, either by striking from or adding to the names of the said list, leaving names not exceeding in number the officers to be elected, or by preparing a new list, signing said altered or prepared ballot with his name, and either mailing it to the Secretary or presenting it in person at the annual meeting; *Provided*, that no member or associate in arrears since the last annual meeting shall be allowed to vote until the said arrears shall have been paid. The ballots shall be received and examined by three Scrutineers, appointed at the annual meeting by the presiding officer; and the persons who shall have received the greatest number of votes for the several offices shall be declared elected, and the Scrutineers shall so report to the presiding officer. The ballots shall be destroyed, and a list of the elected officers, certified by the Scrutineers, shall be preserved by the Secretary.

VI.

MEETINGS.

The annual meeting of the Institute shall take place on the third Tuesday of February, at which a report of the proceedings of the Institute and an abstract of the accounts shall be furnished by the Council. Two other regular meetings of the Institute shall be held in each year, at such times and places as the Council shall select, and notice of all meetings shall be given by mail, or otherwise, to all members and associates, at least twenty days in advance. Special meetings may be called whenever the Council sees fit; and the Secretary shall call a special meeting on a requisition signed by fifteen or more members. The notices for special meetings shall state the business to be transacted, and no other shall be entertained.

Every question which shall come before any meeting of the Institute, shall be decided, unless otherwise provided by these Rules, by the votes of a majority of the members then present. Any member or associate may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

VII.

PAPERS.

The Council shall have power to decide on the propriety of communicating to the Institute any papers which may be received, and they shall be at liberty, when they think it desirable, to direct that any paper read before the Institute, shall be printed in the Transactions. Intimation, when practicable, shall be given, at each general meeting, of the subject of the paper or papers to be read, and of the questions for discussion at the next meeting. The reading of papers shall not be delayed beyond such hour as the presiding officer shall think proper; and the election of members or other business may be adjourned by the presiding officer, to permit the reading and discussion of papers.

The copyright of all papers communicated to, and accepted by, the Institute, shall be vested in it, unless otherwise agreed between the Council and the author. The author of each paper read before the Institute shall be entitled to twelve copies, if printed, for his own use, and shall have the right to order any number of copies at the cost of paper and printing, provided said copies are not intended for sale. The Institute is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions at its meetings, and it is understood that papers and discussions should not include matters relating to politics or purely to trade.

VIII.

AMENDMENTS.

These Rules may be amended at any annual meeting by a two-thirds vote of the members present; *Provided*, that written notice of the proposed amendment shall have been given at a previous meeting; *and Provided, also*, that the amendment or amendments so adopted shall be printed upon a ballot and sent, not later than the next distribution of printed matter, to all members and associates not in arrears for the preceding year (except honorary members and foreign members elected before February, 1880), and each person receiving the same shall be requested to return it to the Secretary with his written vote of Yes or No to each amendment, and his signature; and the President shall appoint as scrutineers three members or associates, who shall examine all of the said ballots which shall have been returned within one month from the date of their distribution, and shall report the result; and the Secretary shall publish and distribute to members, not later than the next distribution of printed matter, an announcement of the said result so reported, together with the text of the additional or amended rule or rules so adopted; and the amendment or amendments approved by the majority of the ballots so returned and reported shall become part of these rules from and after the publication of said announcement by the Secretary.

PROCEEDINGS OF THE SIXTY-FIFTH MEETING, BEING PART OF THE INTERNATIONAL ENGINEERING CONGRESS, CHICAGO, AUGUST, 1893.

(Condensed from the full report, in vol. xxii.)

AT a joint session of Divisions C and D, held July 31st, the following papers were presented:

The Growth of American Mining Schools, and their Relation to the Mining Industry, by Prof. S. B. Christy, Berkeley, Cal.

*Mining and Mineral Statistics, by C. Le Neve Foster, Llandudno, Wales.

Genesis of Ore-Deposits, by Franz Pošepný, Vienna, Austria.

*Geological Distribution of the Useful Metals in the United States, by S. F. Emmons, Washington, D. C.

*Lead- and Zinc-Deposits of the Mississippi Valley, by W. P. Jenney, Deadwood, S. Dak.

*Mineral Deposits of Southwest Wisconsin, by W. P. Blake, Shullsburg, Wis.

*Origin of the Gold-bearing Quartz of the Bendigo Reefs, Australia, by T. A. Rickard, Denver, Colo.

*A Remarkable Deposit of Ores of Wolfram in the United States, by Dr. Adolph Gurlt, Bonn, Germany.

Division C subsequently held separate sessions, as follows:

WEDNESDAY MORNING, AUGUST 2d.

Papers presented:

*The Detection and Measurement of Fire-Damp in Mines, by Prof. G. Chesneau, École des Mines, Paris, France.

*The Hydrogen-Oil Safety-Lamp, by Prof. Frank Clowes, Nottingham, England.

Experimental Investigations on the "Loss of Head" of Air-Currents in Underground Workings, by D. Murgue, Bessèges, France.

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* Printed in vol. xxii.

THURSDAY MORNING, AUGUST 3D.

Papers presented:

*The Bertha Zinc-Mines, by W. H. Case, Bertha, Va.

*General and Special Observations Concerning Ore-Dressing, by O. Bilharz, Berlin, Germany.

*An Improved Hanging Compass, by Guy R. Johnson, Longdale, Va.

FRIDAY MORNING, AUGUST 4TH.

Papers presented:

*A Furnace with Automatic Stoker, Travelling Grate and Variable Blast, Intended Especially for Burning Small Anthracite Coals, by Eckley B. Coxe, Drifton, Pa.

*Tests of Hydraulic Materials, by Professor H. Le Chatelier, Paris, France.

Electricity in Mining, by Francis O. Blackwell, Lynn, Mass.

Division D held separate sessions as follows:

TUESDAY MORNING, AUGUST 1ST.

Papers presented:

*Summary of American Improvements and Inventions in Ore-Crushing and Concentration, and in the Metallurgy of Copper, Lead, Gold, Silver, Nickel, Aluminum, Zinc, Mercury, Antimony and Tin, by James Douglas, New York City.

*Note on Experiments on the Specific Gravity of Gold Contained in Gold-Silver Alloys, by Henry Louis, Singapore, Straits Settlements.

The Limitations of the Gold Stamp-Mill, by T. A. Rickard, Denver, Colo.

*Improved Slag-Pots, by H. A. Keller, Butte, Montana.

*The Separation of Blende from Pyrites; a New Metallurgical Industry, by W. P. Blake, Shullsburg, Wis.

WEDNESDAY MORNING, AUGUST 2D.

Papers presented:

*Microscopic Metallography, by F. Osmond, Paris, France.

Microstructure of Ingot-Iron in Cast Ingots, by Professor A. Martens, Berlin, Germany.

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* Printed in vol. xxii.

*Segregation and its Consequences in Ingots of Steel and Iron, by Alexandre Pourcel, Paris, France.

*Microstructure of Steel, by Albert Sauveur, South Chicago, Ill.

Further Observations on the Relations between the Chemical Constitution and the Physical Character of Steel, by William R. Webster, Philadelphia, Pa.

Heat-Treatment of Steel, by H. M. Howe, Boston, Mass.

THURSDAY MORNING, AUGUST 3D.

Papers presented:

*The Bessemer Process, as conducted in Sweden, by Prof. Richard Åkerman, Stockholm, Sweden.

*The Open-Hearth Process, by H. H. Campbell, Steelton, Pa.

Iron-Alloys, with Special Reference to Manganese Steel, by R. A. Hadfield, Sheffield, Eng.

Consumption of Fuel in the Taylor Gas-Producer Plants at the Aspen and Marsac Mills Compared, by C. A. Stetefeldt, San Francisco, Cal.

FRIDAY MORNING, AUGUST 4TH.

Papers presented:

Review of American Blast-Furnace Practice, by E. C. Potter, Chicago, Ill.

A New Process for the Production of Pig-Iron, Refined Iron, Ingot-Metal and Weld-Metal, by Alexander Sattmann and Anton Homatsch, Donawitz, Austria.

Sulphur in Cast-Iron, by W. J. Keep, Detroit, Mich.

*Blowing-Engines, by Julian Kennedy, Pittsburgh, Pa.

Recent Advances in Pyrometry, by Prof. W. C. Roberts-Austen, London, Eng.

* Printed in vol. xxii.

PAPERS.

A NEW PROCESS FOR THE PRODUCTION OF PIG-IRON, REFINED IRON, INGOT-METAL AND WELD-METAL.

BY ALEXANDER SATTMANN AND ANTON HOMATSCH, METALLURGICAL ENGINEERS, DONAWITZ, STYRIA, AUSTRIA.*

(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

INTRODUCTION.

IN view of the great progress made in the last few decades in blast-furnace and refining processes, the idea of supplanting these modes of manufacture by any other appears extremely venturesome. As our proposition amounts to nothing less than this, we shall, above all things, endeavor to clearly set forth our reasons for entering upon and perfecting our plan.

The fundamental conditions for the healthy development of an iron-industry in any district are good communications, suitable ores, and proper fuel. It is only in exceptional instances that all these favorable factors are combined. In many localities, suitable blast-furnace fuel does not occur near the iron-ores, so that, in the manufacture of pig-iron heavy transportation-charges frequently have to be levied on the product, thus raising the cost of production very appreciably, and sometimes committing to unstable freight-rates the financial success of the enterprise. As pig-iron is made in all but exceptional cases, where peculiar conditions favor the profitable working of a direct process, it is obvious that any increase or reduction in the cost of manufacturing pig-iron must exert a wide influence on the iron-industry. If we examine into the treatment of the pig-iron, we find that in transferring it to the refining-chamber, even where so-called direct blast-furnace metal is used, and in carrying out any one of the various refining-methods, considerable losses of heat are incurred.

The most efficient utilization of heat occurs in the converter-processes—at the cost, however, of a special composition of the pig-iron, requiring the consumption of more fuel in the blast-furnace. Far greater losses of heat are connected with the reverberatory or open-hearth processes. In these, the oxidizing and heating gases do not

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* Translated by W. B. Kunhardt, New York City.

impinge directly on the metal, since the latter lies at greater or less depth beneath a blanket of slag; the thermal and chemical effects of the flame, therefore, are produced indirectly, and a certain loss of heat attends the transfer, so that the fuel-consumption is large in proportion to the product, and the process is slow. Very high temperatures, and, possibly, mechanical agitation, may accelerate the process, but they will likewise enhance its cost—particularly mechanical agitation, which can be satisfactorily performed only by the direct application of manual labor.

These considerations have led us to propose a process for the production of pig-iron in which gas is substituted for the usual solid blast-furnace fuel. If the resulting pig-metal is to be converted into a more decarburized material, a refining-process is provided for in immediate connection with the smelting, so that the molten pig-iron, flowing by gravity to a collecting-chamber, may encounter oxidizing and heating gases which effect the fining (desiliconizing), and refining (decarburizing) to the desired extent. The final product may be turned over at once to mechanical manipulation, or may be a well-prepared material for a further finishing process. In connection with the following description of the process, an example of its practical application will be shown, and the thermal balance-sheet based upon that example, will serve as a test of the profitableness of the process.

Description of the Process.

There are four phases to the process:

1. Heating of the ore and flux, and, if necessary, calcining the ore with gas-fuel.

2. Reduction of the ore, and carburization of the resulting iron-sponge with reducing gas.

3. Melting of the carburized iron sponge by the direct combustion of solid fuel.

4. Separation of the slag from the resulting pig-iron, and refining with oxidizing gases immediately after the melting, thereby producing a more or less carburized metal.

Whether the ore is calcined in separate ovens or in the reduction-furnace will depend on local conditions, and especially on the nature of the ore. Here, it is assumed that the calcination takes place in the reduction-furnace.

The Gases Used in the Process.—The process may be carried on with natural gas, or with artificial fuel-gas produced either by the

vaporization of liquid fuel or by the dry distillation or partial combustion of solid fuel, or finally, with waste-gases derived from the process itself. As a rule, the utilization of the waste-gases will prove highly advantageous wherever natural gas does not exist, and the production of a fuel-gas of low nitrogen-content is costly. Regarding this utilization, it should be borne in mind that in reducing the ore, the gas takes oxygen from it, and thus eventually attains a higher percentage of oxygen, and less nitrogen, than atmospheric air, or than gas produced by partial combustion with air. Upon conducting the gas, derived from the reduction, over incandescent carbon (above 900° C.), it takes up an amount of carbon corresponding to its excess of oxygen, and thus again the percentage of nitrogen is reduced. If the gas could be thus continuously used for repeated deoxidations and saturations with carbon (recuperation), it would soon contain scarcely any nitrogen; but, in order to effect the reduction, it is necessary to generate a certain amount of heat by burning a part of the gas with atmospheric air, and for that reason the nitrogen-content, instead of dropping nearly to *nil*, will become a constant, which, however, will certainly be lower than that of gases produced by partial combustion. A calculation based on the reduction of Fe_3O_4, by our intermittent process (page 6), shows that where the composition of the reducing-gas has reached a constant, the gas will contain 37 per cent. by weight of nitrogen, as against 53.4 per cent. of nitrogen, as a minimum in blast-furnace gases, and 62.8 per cent. in producer-gas.

The absorption of heat during deoxidation may also be repaired by burning solid fuel; but the use of a comparatively expensive combustible, employed otherwise for melting only, is thereby increased, though, at the same time, the deoxidizing power of the gases is raised by reason of the diminished proportion of nitrogen. Whether this advantage more than offsets the greater cost, experience only can determine.

In calcining carbonates the escape of carbon dioxide from the ore increases the proportion of oxygen in the gas; by the repeated recuperation and utilization, a gas of very low nitrogen-content is eventually produced. Obviously a gas so poor in nitrogen and so rich in carbon monoxide must accelerate the reduction of the ore, or if burned for other purposes, the results must be particularly favorable, since the products of combustion will contain less than the usual amount of nitrogen, and hence less heat will be carried off through the stack.

With gases of the above described character the ore is pre-heated, calcined (if necessary) and deoxidized, and the resulting iron sponge is duly carburized.

Melting of the Iron Sponge.—Immediately after the sponge is formed by the reducing action of the gas it is melted in a hot non-oxidizing atmosphere, resulting, as in the blast-furnace, from the the combustion of a solid, highly carbonaceous fuel. Since this fuel burns in front of the blast-tuyeres principally to carbon dioxide, which would promptly oxidize the iron sponge, a layer of incandescent fuel of sufficient thickness must be provided between the sponge and the tuyeres to convert the greater part of the carbon dioxide into monoxide before it reaches the sponge. The surplus heat from the combustion and subsequent reduction suffices to melt the sponge and form a slag of the gangue and flux.

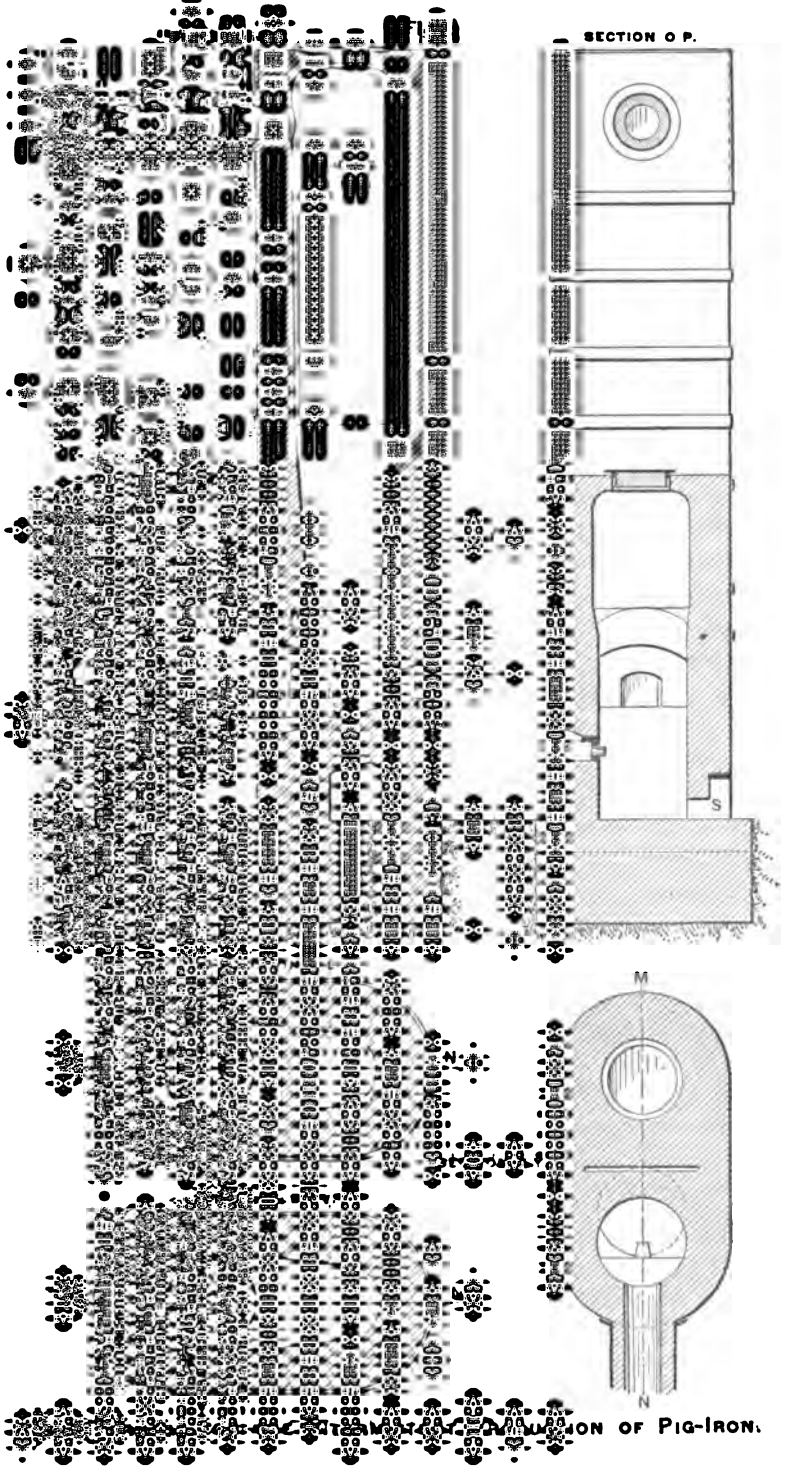
During the melting-period the process differs in no essential respect from that of the blast-furnace, except that solid fuel does not come in contact with the iron-bearing portion of the charge until this is in the form of a finished, melting sponge. The reduction of the more refractory elements cannot take place until the iron sponge commences to melt and the slag begins to form.

Refining of the Pig-Iron.—Assuming that with a view to fuel economy, the pig-iron has been made with a very low content of carbon, silicon and phosphorus, it cannot be satisfactorily treated in a converter. If, therefore, it is to be fined (desiliconized) or partly refined (decarburized), that is to say, if the foreign elements are to be removed, the metal, on its way to the collecting-chamber after the removal of the slag, is brought into intimate contact with hot, heat-producing and intensely oxidizing gases. Thus the foreign elements are wholly or partly eliminated. By maintaining a sufficiently high temperature in the collecting-chamber to preserve the material in a molten state during the progress of the decarburization, the product, depending on the extent to which the refining is carried, will be refined pig-iron, ingot-steel or ingot-iron. With a lower temperature in the collecting-chamber than the melting-point of the intended product, weld-metal will be produced.

Working of the Process.

Intermittent Working.

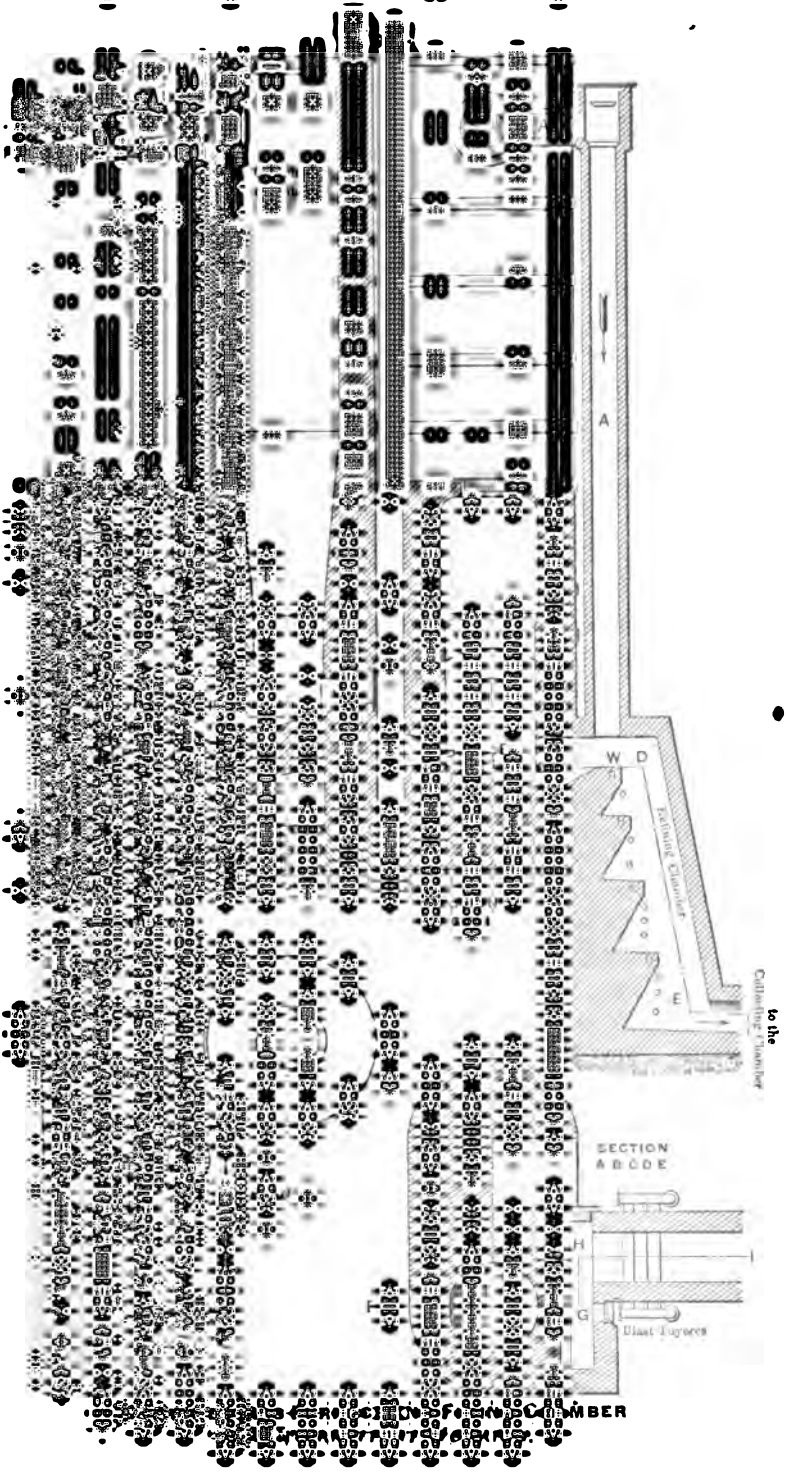
There are two ways of carrying on the process, either by intermittent or continuous working. By the intermittent plan the pro-



ON OF PIG-IRON.

cess is conducted upon a single furnace-charge; the preparation, reduction and melting being carried on successively, and the refining being performed simultaneously with the melting. After the completion of the melting, the furnace is empty and ready for another charge. Obviously fresh gas will be required to start the process unless the plant consists of several furnaces, when the surplus gases from another furnace may be used. For refining, the waste-gases from the simultaneously conducted melting-operation may be burned with a large excess of air. Several modifications of this system of working are practicable, and two cases will be described, in both of which the utilization of the waste-gases is assumed.

First Case.—Fig. 1 shows a furnace for the production of pig-iron only. Fig. 2 shows a similar furnace with a refining-chamber attached. The ore and flux are charged into a vertical chamber, the bottom of which inclines toward the melting-chamber and extends sufficiently far into it to allow the ore to accumulate on its natural bosh-angle without rolling into the hearth. The throat of the furnace can be closed gas-tight; below it is the off-take A for the waste-gases. A chamber for solid fuel is placed beside the charging-chamber, and is likewise furnished with a gas-tight cover for the charging-hole, below which is the gas supply-pipe Z. The lower part of this chamber merges into the melting-chamber. Both these chambers are connected with the ore-chamber through the archway O_1, opposite which there is a sealed opening O_2, to be used in emergencies for loosening obstructions or for repairing the bottom. The melting-chamber is fitted with a blast-tuyere D, a cinder-notch F, at a slightly lower level, and a tap-hole S at the bottom for drawing off the metal. In Fig. 2 the tap-hole is replaced by a connection with the refining-chamber. The dam W keeps a certain quantity of metal on the hearth, and the tymp-arch T prevents the overflow of slag into the refining-chamber. The latter has a step-bottom and is connected with the collecting-chamber by means of a short flue. Above the dam W, the waste-gases drop through the down-take A into the refining-chamber, mixing there with an air-blast which is delivered through a number of lateral tuyeres. The general arrangement of such a furnace, in connection with recuperators for the waste-gases, is shown in Fig. 3. The gas-pipe A branches to two recuperators R_1 and R_2, each branch being fitted with a valve to control the course of the gas. A steam-jet D in front of each recuperator produces a circulation through the system. From the recuperators two branch-pipes Z, provided with valves, conduct the re-

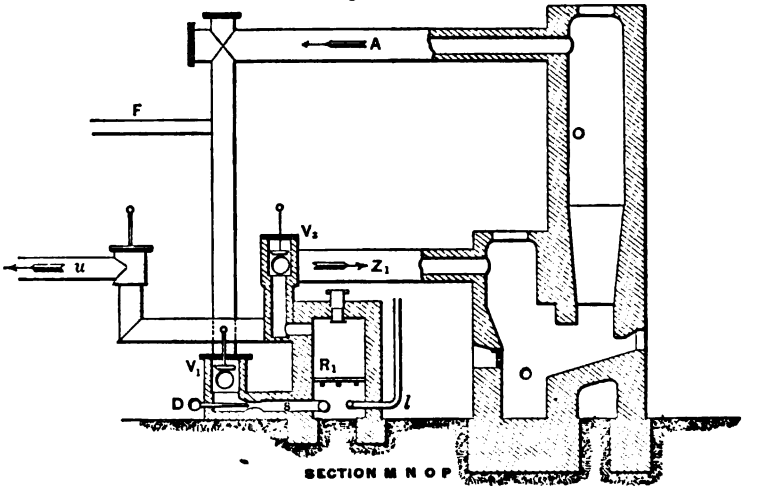


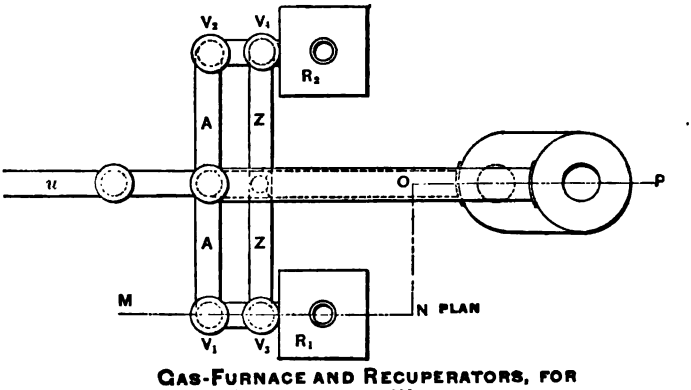
SECTION OF IN SUMMER

cuperated gas to the main Z_1. This main is tapped by a branch-pipe u and a similar branch F taps the waste-gas main A to allow surplus gas to be carried off and consumed at other points.

The recuperators are operated as follows: Waste-gases from the

Fig. 3.





GAS-FURNACE AND RECUPERATORS, FOR INTERMITTENT WORKING.

pipe A flow through the open valve V_1 and are forced by the steam-jet D into the recuperator R_1; here they pass through incandescent carbon (above 900° C.) and are recuperated, that is to say, the carbon-dioxide is converted into carbon-monoxide. Reducing-power being thus imparted to the gases, they leave the recuperator and pass through the valve V_2 into the gas-main Z, and thence to the fur-

nace. Meanwhile, the valves V_2 and V_4 are closed, and the recuperator R_2 is being heated by the combustion of coal with air supplied through the blast-pipe I. The products of this combustion, after delivering their waste-heat to a fire-brick heater, escape to the stack. After the temperature of the fuel in the recuperator R_1 has fallen to the lowest permissible limit, the alternate recuperator R_2 is brought into service by shutting off its connection with the blast and stack and opening the valves V_2 and V_4. Valves V_1 and V_3 of the cooled recuperator R_1 are then closed, and the blast and draught are turned on to heat it. In the new period, therefore, the gases are recuperated in R_2, while the fuel is heated in R_1. As the quantity of gas is increased by recuperation, a surplus will be available for heating hot-blast stoves, generating steam for the blowing-engines, the steam-jet and various steam-motors, as well as for calcining the ore where this operation is performed in separate furnaces.

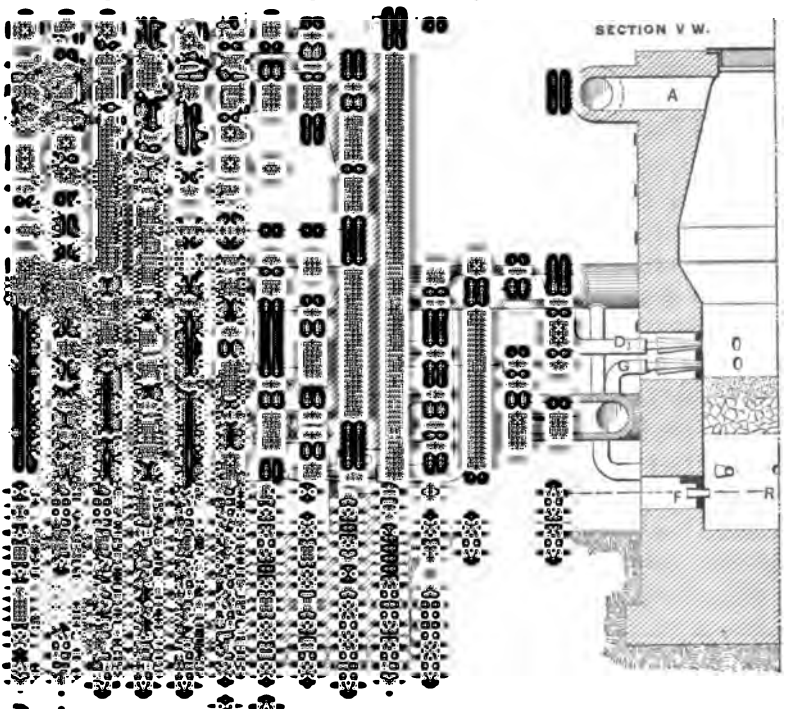
With the furnaces shown in Figs. 1 and 2 the process is conducted as follows: the ore-mixture and flux are charged together, the latter being added in proper proportion to slag the gangue and also the ash of the solid fuel required in the melting-stage of the process. The furnace-top is then sealed, and reducing-gases are admitted through the pipe Z, and blast through the tuyere D. Ordinarily the furnace will have retained a sufficient temperature from the preceding charge to ignite the gas; otherwise burning fuel should be placed in the melting-chamber and blast should be introduced to insure the ignition of the gas. The products of combustion, which are either neutral or oxidizing, according to the proportion of gas and air admittted, pass under the archway O_1 into the charging-chamber and there heat the ore and flux, expelling carbon-dioxide if present, and escape through the off-take A to the recuperator. When the ore has been sufficiently prepared in this manner, the blast is partly or entirely shut off, and a current of reducing-gas passes alone through the charge and deoxides the ore. If this action reduces the temperature too much, the supply of heat may be replenished by burning a portion of the gas or an adequate amount of solid fuel with blast supplied through the partly opened tuyere D. Upon completion of the reduction, the gas and blast are both shut off and solid fuel is charged into the fuel-chamber—an operation that may, indeed, be attended to at the close of the calcining-period. As soon as the fuel has been charged, the fuel-hopper is closed and the blast is turned on. The hot gases of combustion pass through the opening O_1 and melt the iron sponge on the bottom of the charging-

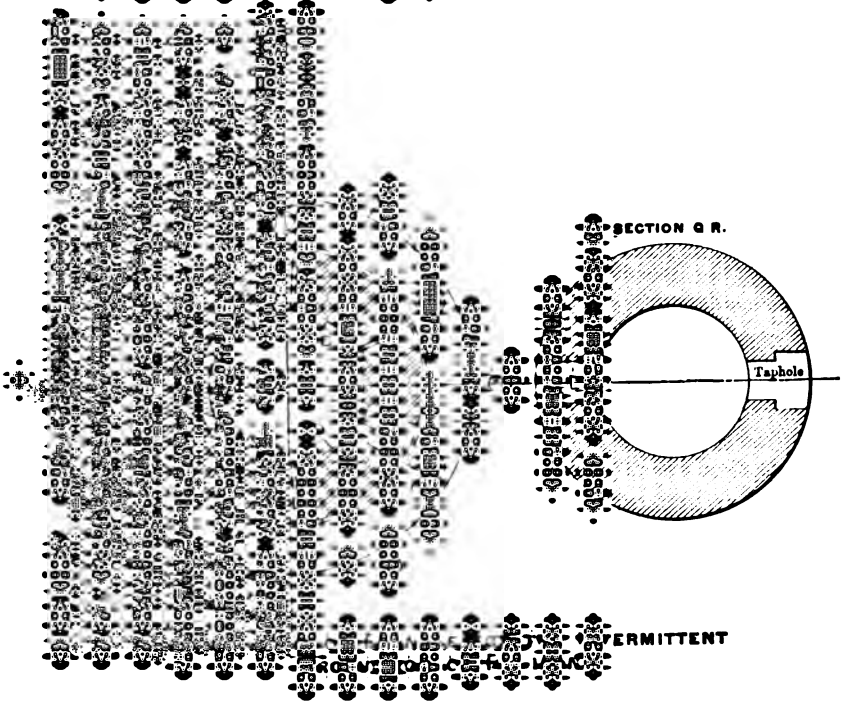
or ore-chamber. As room is thus made below, the sponge in the upper part of the chamber settles down and is melted in turn. The molten pig-iron and slag flow into a hearth or well, the ash of the fuel combining with the slag as the latter meets it. When the level of the bath has risen above the cinder-notch, the slag is tapped, and from that time forth until the end of the heat it flows continuously. The metal is tapped only after the entire charge has been melted. Then all necessary repairs are made, and the furnace is ready for another heat. During melting, the waste-gases may be utilized for various purposes without any recuperation.

In the furnace shown in Fig. 2, a portion of the waste-gas is carried through a vertical down-take A into the refining-chamber where it is burned with air delivered through laterally disposed tuyeres. The pig-metal and slag collect in the well of the melting-chamber; as soon as the metal reaches the top-plate of the dam W it overflows, and falls in cascades, finely divided, through the refining-chamber, where it meets with the air-blasts which oxidize its foreign elements. Since some of the waste-gas is burned in this chamber, the temperature of the descending metal is raised, thus keeping pace with the advancing melting-point due to its progressive decarburization. The refined metal and the flame both pass through the outlet-flue to the collecting-chamber. The tymp-arch T prevents the overflow of slag into the refining-chamber; it is drawn off through the cinder-notch, as before. Upon completion of the heat, the metal and cinder remaining in the furnace are drained off through a tap-hole provided for that purpose.

Second Case.—The furnace, Fig. 4, is designed for the production of pig-iron only, though it may be connected as in Fig. 2 with a refining-chamber. The ore-chamber is provided with a gas-tight cover, below which is the off-take A. In the lower part of this chamber are the blast-tuyeres D_1 and gas-tuyeres G, the latter delivering gas from the supply-pipe Z. Below these tuyeres the charging-chamber merges into the fuel-chamber, the lowest portion of which forms the sump or well, at the bottom of which is the tap-hole, and at proper levels, the cinder-notch F and blast-tuyeres D, the latter furnishing air to burn the solid fuel.

The process is conducted as follows: Solid fuel is charged in proper quantity, and if the furnace is cold, live coals are spread at the level of the blast-tuyeres. The fuel is covered with a blanket of fine ore which does not reach above the gas-tuyeres G. Upon this the usual charge of ore and flux is made, and the top is then tightly closed. In


SECTION V W.
A
D
G
F
R


SECTION G R.
Taphole
ERMITTENT

starting a cold furnace, hot air is forced through the blast-tuyeres D and through the fuel-bed, until the temperature at the gas-tuyeres has risen to the igniting-point of the gas. At this temperature, due either to the residual heat of the preceding charge or attained by burning some of the fuel, combustible gas is admitted through the gas-tuyeres G, and air through the blast-tuyeres D_1, in such proportions that the resulting flame may be either oxidizing or neutral as desired. After having completely dried, or calcined the ore, as the case may have been, the blast is wholly or partly turned off and the current of gas deoxidizes the ore. The heat required for this purpose may be supplied, as before, by burning a portion of either the gas or the solid fuel. In the former case the blast for combustion is admitted through the upper tuyeres D_1, in the latter case through the lower tuyeres D.

When the reduction has been accomplished, hot-blast is admitted through the tuyeres D, consuming the solid fuel and melting down the iron sponge. The metal and slag collect in the hearth and gradually raise the fuel to the level of the tuyeres. After the slag has risen above the cinder-notch, it is tapped and flows continuously until the end of the heat. As soon as the whole charge has been melted, the metal is tapped, and a fresh charge is immediately made. Where a refining-chamber is connected with the furnace, an excess of solid fuel should be charged, in order that there may be sufficient coal above the tuyeres until the very end of the melting-period to reduce all carbon-dioxide formed at the tuyeres. This surplus fuel remains in the furnace at the end of the heat, and is used in the succeeding one.

Arrangement of Plant and Structural Details.—Several modifications of the intermittent system are practicable, so long as the principle is adhered to of heating, calcining and deoxidizing the ore with gas and reserving the use of solid fuel for melting only. In a plant of several furnaces, provision may be made to pass the waste-gases of one furnace through a recuperator to a second furnace, and thence through another recuperator to a third furnace and so on, until finally they are carried to the stack. In such an arrangement, no circulating apparatus (steam-jet) would be required.

The furnace is built of fire-brick, but the inclined bottom (Figs. 1 and 2) should be preferably of neutral or basic material. The tuyeres, tuyere-plates and cinder-notch are water-cooled, as in the blast-furnace. The gas-flues to and from the recuperators are lined with a non-conductor in order to reduce the loss of heat to a minimum.

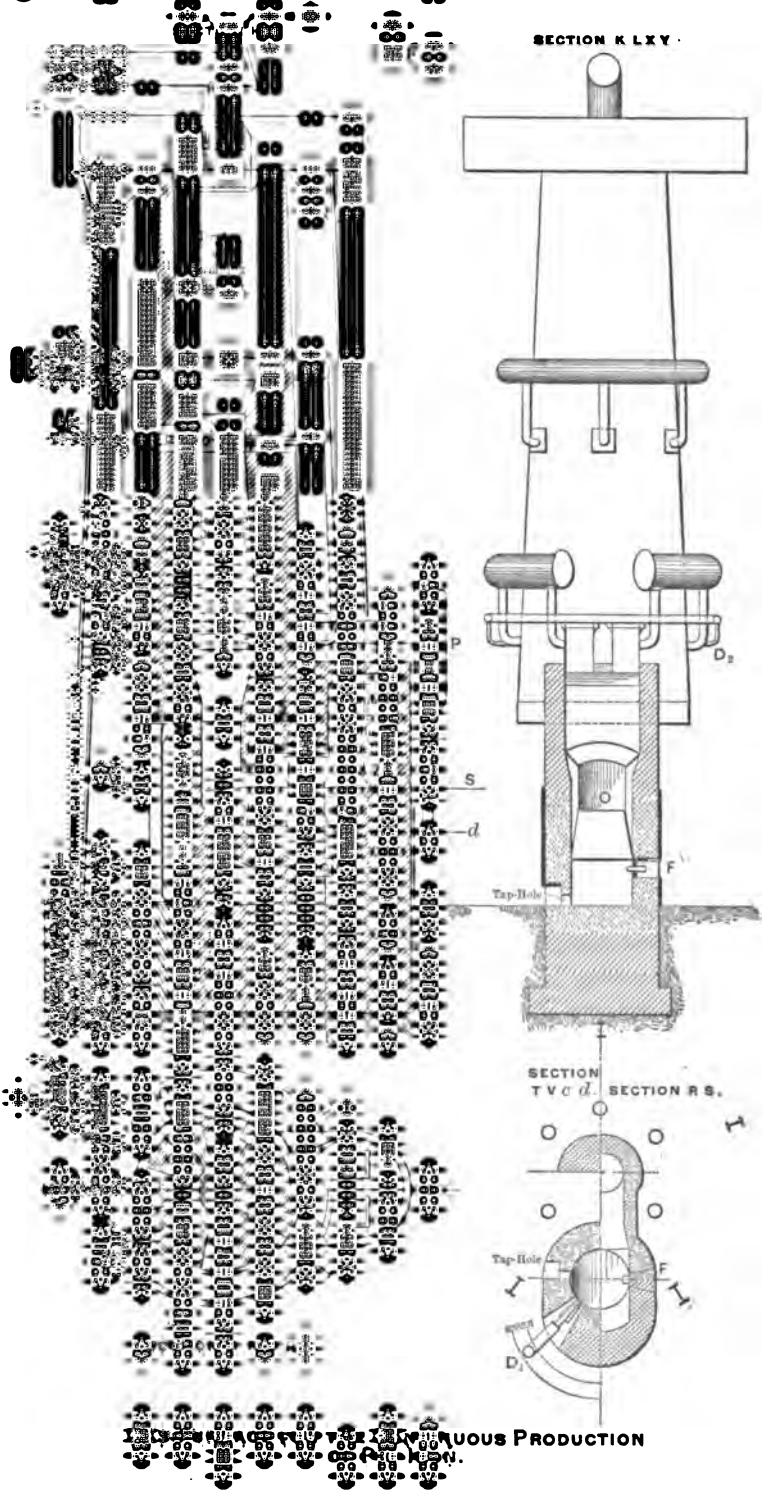
Porous bricks, made by mixing clay with saw-dust and then burning, answer the purpose well and are to be recommended for lightness. The various valves are water-cooled, and cooling-pipes are set in the brick-work to protect the edges of the step-hearth of the refining-chamber.

In each of the several modes of working, the extent of the reduction, the temperature, and the rapidity of melting may be controlled, and where refining also is carried on, that likewise is subject to control, so that in practice any of the final products enumerated in the title of this paper may be produced at the will of the operator. Intermittent working is applicable where the production is to be quite limited. The cost of a plant is small. A furnace having a charging-chamber of 8 to 12 cubic meters (10 to 15 cubic yards) capacity will produce about 10 tons of metal per heat. The number of heats per day will depend largely on the reducibility of the ore. By using recuperated gas of great deoxidizing power, we may assume that four heats of easily reducible ore, or three of less easily reducible ore, may be run in a day. The total fuel-consumption, including requirements for roasting, heating the blast, and generating steam, amount to 29 kilos of fir-charcoal and 123 kilos of lignite (with a heating-capacity of about 5000 calories) per 100 kilos of refined iron. In calculating this result, all losses of heat have been scrupulously considered, and allowances have been made which, if anything, are too liberal.

Continuous Working.

In this system of operating, all four of the above-described phases or steps of the process are conducted simultaneously. The movement of the charge is opposed in direction to that of the gases acting upon it, so that the process benefits by all the important advantages incident to that relation. Viewed from the standpoints of both chemical and thermal efficiency, the energy of the gaseous reagents is more completely absorbed. This system, like the former, may be applied in several ways; here we shall undertake to describe two plants, differing principally in the methods by which the solid fuel is supplied.

First Plant.—Fig. 5 represents a furnace furnished with blast-tuyeres W for the drying- and calcining-chamber. If the ores do not require to be calcined, this chamber may be of smaller dimensions than those shown. It is provided with a gas-tight charging-hopper, through which passes a central off-take A for the waste-gases.

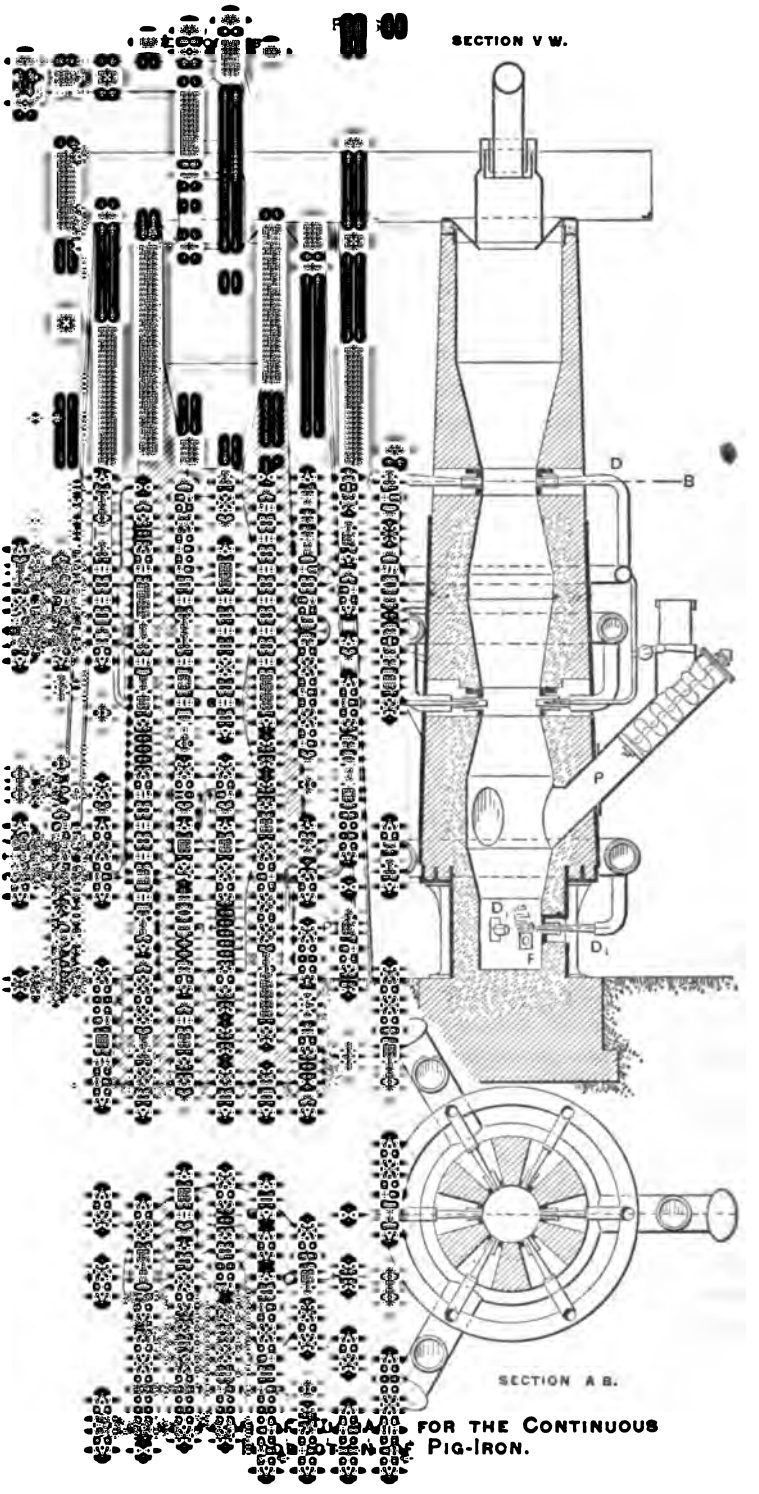


[illegible] CONTINUOUS PRODUCTION

The drying- and calcining-chamber connects below with the reducing-chamber, in which there are several duplex tuyeres, the inner nozzles D_2 supplying air-blast and the outer concentric ones supplying gas. The bottom of the reducing-chamber is inclined toward the melting-chamber, and extends so far into it that the iron sponge may rest with its natural slope upon the bottom and not roll into the adjoining well of the melting-chamber. The chamber for solid fuel merges into the melting-chamber, and connects with the reducing-chamber, as shown. It likewise is provided with a gas-tight charging-hopper, through which the solid fuel is introduced. The melting-chamber is fitted with blast-tuyeres D_1, a cinder-notch F, and a tap-hole. If the pig-iron is to be refined, the tap-hole is replaced by a tymp-arch and a dam in immediate connection with the refining-chamber.

In working the furnace, solid fuel is burned in the melting-chamber by the blast of the tuyere D_1, and in proportion as it is consumed more fuel is charged through the hopper. The hot gases of combustion pass through the bed of fuel and encounter the iron sponge at O_1, melting it and likewise melting the slag. The pig-iron and slag flow into the well, the ash of the solid fuel being taken up by the slag on the way. The hot, deoxidizing gas from the melting-operation passes into the reducing-chamber and unites there with more deoxidizing gas, introduced through the gas-tuyeres; in the passage through the chamber both gases jointly reduce the charge. In order to provide for the absorption of heat occasioned by the deoxidation, either sufficient blast is admitted through the tuyeres D_2 to burn a portion of the gas, or solid fuel is burned in the melting-chamber in larger quantity than the melting actually demands.

When the gases enter the drying- and calcining-chamber, a further portion is burned with air supplied by the blast-tuyeres D. The heat thus produced prepares the charge by expelling carbon-dioxide, and, in the higher zone, by drying the ore. In traversing this chamber the gases surrender the greater part of their heat, but as they remain fairly combustible, a portion is utilized for heating the blast, while another portion is conducted to the recuperator (supposing natural gas is not used) in order to be enriched with carbon and again utilized in the process. In continuous working, where the gases leave the furnace at a low temperature, circulation may be promoted by a blower introduced into the circuit at a point just ahead of the recuperator. In proportion as the iron sponge is melted



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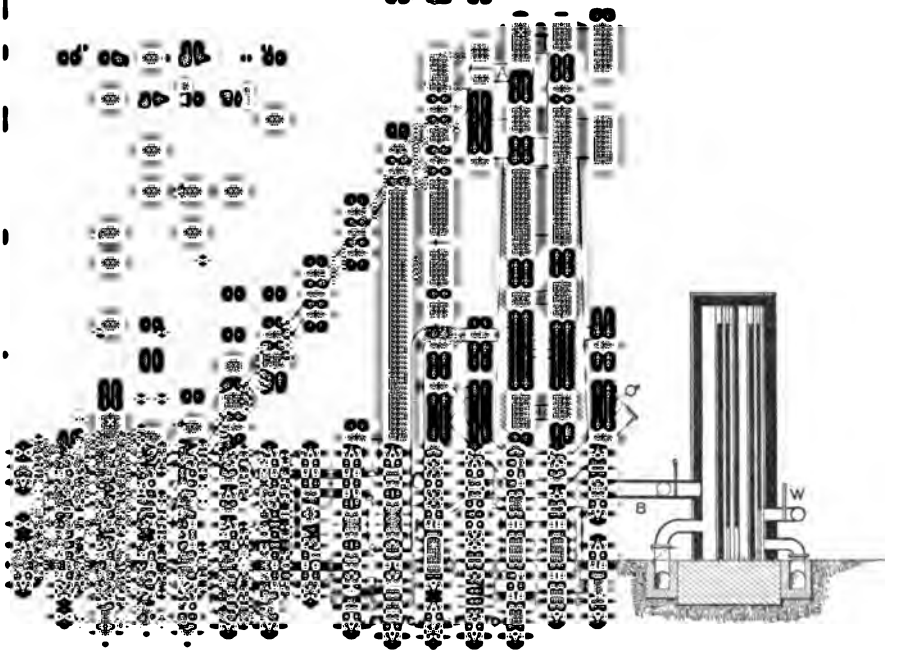
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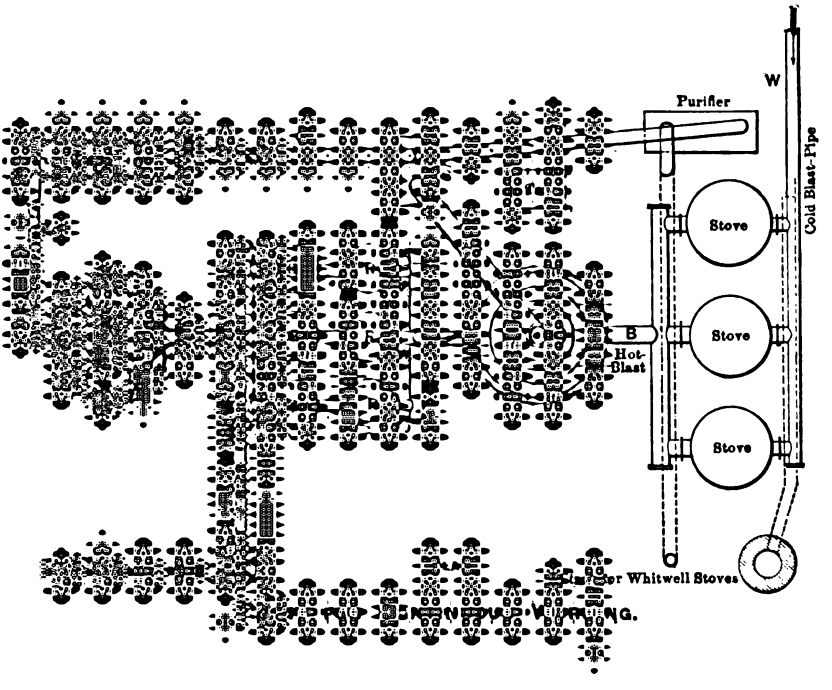
Purifier
W
Cold Blast-Pipe
Stove
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B
Hot-Blast
Whitwell Stoves

away, the entire burden descends, and fresh ore and flux are charged into the empty space formed in the upper chamber.

Second Plant.—The furnace illustrated in Fig. 6 has the same form of drying- and reducing-chambers as the preceding one, but the melting-chamber is set immediately below the reducing-chamber, and is provided with mechanical feeds for the solid fuel. These charging-devices consist of tubes P, through which the fuel is forced by a hydraulic piston or other mechanical contrivance, such as the screw-conveyor shown in the drawing. In the lower part of the melting-chamber there are a number of blast-tuyeres, set, in this case, vertically below the fuel feed-tubes, there being as many tuyeres as there are tubes. A cinder-notch and tap-hole, or a tymp-arch, a dam, and a refining-chamber may be arranged as in the other plants. The working is very similar to that of the first continuous plant; the course and action of the gases, as well as the descent of the charge through the drying- and deoxidizing-chambers, and its successive chemical alterations, are precisely the same. Below the reducing-chamber the solid fuel is forced into the melting-chamber, and there is mixed with the iron sponge from the chamber above. Both descend together to the region of the tuyeres, where the fuel is burnt with hot blast, and the slag is formed and melted with the metal. As the zone of fusion extends some distance above the tuyeres, and the iron sponge is melted as soon as it reaches that zone, it will never descend, as such, to the level of the tuyeres. The burden of the charge is borne by the solid fuel floating on a bath of pig-iron and slag.

Fig. 7 shows a plant for continuous working. The gases leave the furnace by the central off-take F. After passing through the scrubber S, they go in part through a purifier to hot-blast stoves, and in part through another purifier to blowers, which force the gas through heaters G and recuperators R into the hot-gas pipe P and thence into the furnace. The pipes and flues are fitted with the necessary valves for controlling the circulation; the arrows indicate the course as it has been described. Three recuperators and three gas-heaters are contemplated. When one recuperator becomes too cool, the valves are shifted and the gas is passed through one freshly blown. Hot blast is then turned into the cooled recuperator, and the gaseous products are carried over into the gas-heater, where they are burned, the resulting heat being stored in the brick-work of the heater, while the waste-gases go to the stack. Three Whitwell stoves heat the blast.

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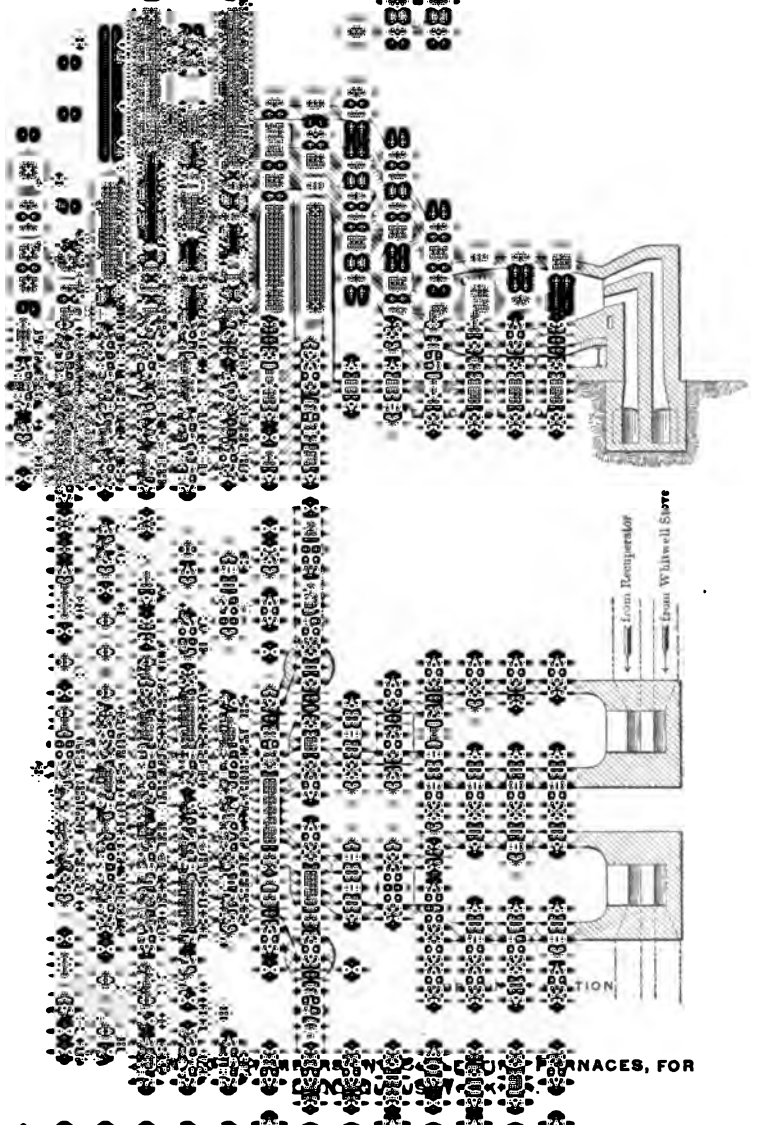

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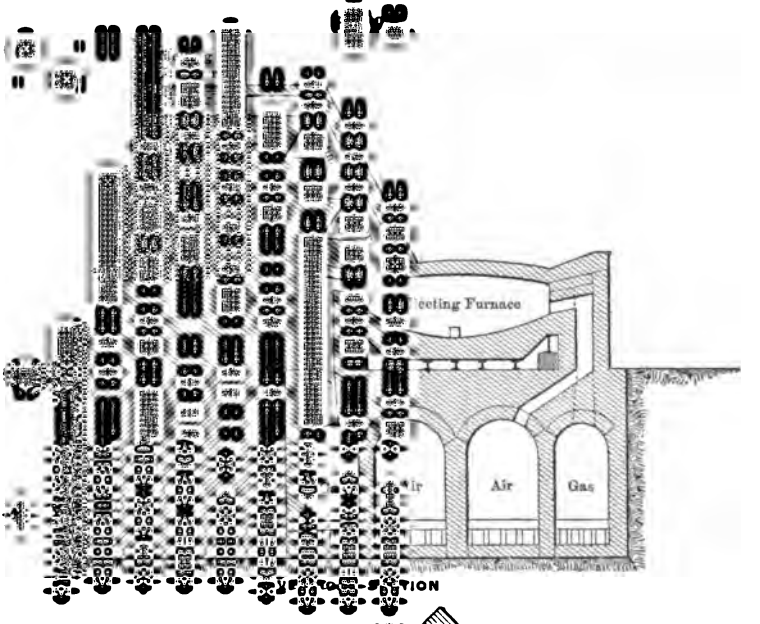

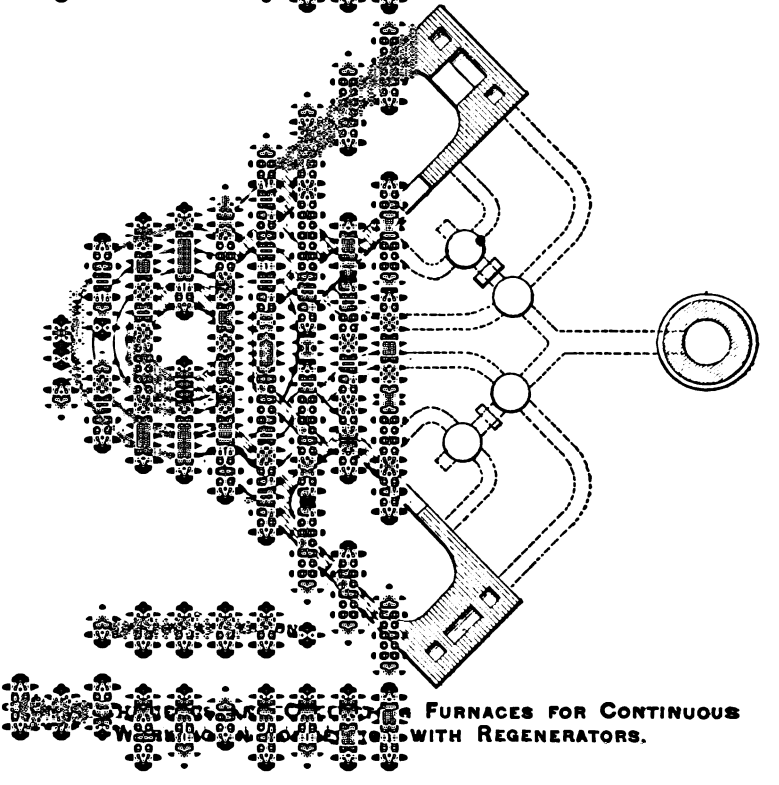

Furnaces for Continuous with Regenerators.

and upward through the refining-chamber to the stack (Fig. 8). The waste-heat may be recovered by steam-boilers placed between the furnace and the stack. In Fig. 9 the collecting-furnaces are of the regenerative type, two being provided for one reduction-furnace, so that either collecting-furnace may be repaired without interfering with the continuous working of the plant. Since with a daily production of 100 tons, an average of only 70 kilogrammes (155 pounds) per minute reaches the collecting-furnace, the working of this furnace may be easily regulated to produce a finished product. It is simply necessary, in computing the charge, to take account of the continual inflow of the refined metal, and toward the close of a heat in the collecting-furnace, to reduce the pressure of the blast in the melting-chamber and thus diminish the flow of metal into the collecting-furnace. During lengthy repairs, the pig-metal would have to be drawn off through a special notch in front of the dam of the melting-chamber.

Structural Details.—Carbon-brick, which have given excellent results in blast-furnace practice, will answer very well as the structural material for continuous furnaces, as far up as the level of the calcining- or drying-chamber. Where an inclined bottom is used (Fig. 5), it should consist of basic material. The dampers and valves for hot air and hot gas are water-cooled, and the step-bottom of the refining-chamber is likewise water-cooled, as previously described. The collecting-chamber is built like a basic, open-hearth furnace.

In both of the foregoing types of continuous-working plants it is practicable to control the composition of the final product by regulating the extent and temperature of the reduction, the rapidity of melting and the point to which the refining is carried. More especially may this control be exercised where the solid fuel is mechanically fed to the furnace (Fig. 6), since by an alteration in the feed the process may be modified at any moment, thus being insured against those casualties which so often disturb the working of the blast-furnace. In an emergency, when a prompt alteration of the slag is desired, it is obvious that the proper flux might be added through the fuel feed-tubes, thus effecting the change in the shortest possible time.

Theoretical Calculations.

In order to show the practicability and profitableness of the process, we have calculated all the results for an assumed case, and show

in detail, in the accompanying fourteen tables, the quantitative thermal and chemical effects of each step. In computing the specific heats of CO_2 and H_2O at different temperatures we have used the formulas of E. Blas,* of Essen; for those of O, N, CO, and H, we have accepted Wedding's values. All figures in the tables are reduced to a basis of 100 kilogrammes of pig-iron product; the figures in the text refer likewise to that basis wherever they do not express percentages. A spathic ore, of the class mined in large quantities at the Styrian *Erzberg* (Ore Mountain), in Austria, is assumed as our raw material. It contains:

	Per cent.
FeO,	49.10
Fe_2O_3,	0.06
MnO,	2.95
MgO,	1.55
CaO,	1.90
Al_2O_3,	1.60
SiO_2,	4.25
CO_2,	34.35
H_2O,	4.24

In order to obtain a fusible slag, clay-slate from a locality near the *Erzberg* is taken as flux. It contains:

	Per cent.
Fe_2O_3,	4.00
CaO,	0.53
Al_2O_3,	14.48
SiO_2,	80.99

For the composition of the coke an average analysis of Silesian coke is taken, namely:

	Per cent.
C,	86.000
H_2O,	4.200
SiO_2,	1.375
Fe_2O_3,	2.090
Al_2O_3,	0.876
Mn_3O_4,	0.070
CaO,	1.955
MgO,	1.078
Na_2O,	0.039
RO,	0.059
SO_3,	2.208
P_2O_5,	0.047

* *Stahl und Eisen*, October, 1892, p. 893.

In tracing the process with the aid of the tables, we shall adhere closely to the course of the gases. In order to melt the iron-sponge (the production of which will be described later), and to reduce the Mn and Si and the metals and metalloids of the coke-ash, the combustion of 30 kilogrammes of coke will be required with blast at 700° Cent. During the melting 0.439 Fe, 2.098 Mn, 0.800 Si, 0.020 S and 0.006 P are reduced (see Table I.), and 0.245 S is sepa-

TABLE I.—*After-Reduction and Melting, to Produce* 100 *Kilogrammes of Pig-Iron.*

Constituents.	Materials Used, Kgs.				Products, Kgs.		
	Iron Sponge.	Coke.	Air.	Totals.	Pig-Iron.	Slag.	Gases.
FeO	0.900	.....	.....	0.900	.....	0.900	.....
Fe_2O_3	.....	0.627	.....	0.627	.....	.....	.....
Fe	92.779	.....	.....	92.779	93.218	.....	.....
MnO	7.199	.....	.....	7.199	.....	4.514	.....
Mn_3O_4	.....	0.021	.....	0.021	.....	.....	.....
Mn	.....	.....	.....	.....	2.098	.....	.....
MgO	3.782	0.323	.....	4.105	.....	4.105	.....
CaO	4.673	0.587	.....	5.260	.....	4.832	.....
Al_2O_3	4.918	0.263	.....	5.181	.....	5.181	.....
SiO_2	16.039	0.413	.....	16.452	.....	14.711	.....
Si	.....	.....	.....	.....	0.800	.....	.....
C	.....	25.800	.....	25.800	3.858	.....	.....
CO	.....	.....	.....	.....	.....	.....	46.998
CO_2	.....	.....	.....	.....	.....	.....	6.600
H_2O	.....	1.260	0.900	2.160	.....	.....	.....
H	.....	.....	.....	.....	.....	.....	0.240
O	.....	.....	27.472	27.472	.....	.....	.....
N	.....	.....	92.032	92.032	.....	.....	92.032
Alk	.....	0.030	.....	0.030	.....	0.030	.....
SO_3	.....	0.662	.....	0.662	.....	.....	.....
S	.....	.....	.....	.....	0.020	.....	.....
P_2O_5	.....	0.014	.....	0.014	.....	.....	.....
P	.....	.....	.....	.....	0.006	.....	.....
CaS	.....	.....	.....	.....	.....	0.551	.....
Total	130.290	30.000	120.404	280.694	100.000	34.824	145.870

rated from O and combined with Ca. The slag amounts only to 34.824 kilogrammes, since the coke consumption is very small and the ore is very pure. The slag contains:

	Per cent.
FeO,	2.584
MnO,	12.961
MgO,	11.787
CaO,	13.875
Al_2O_3,	14.878
SiO_2,	42.244
$Na_2O + RO$,	0.086
CaS,	1.583

In this slag the ratio of the O of the bases to the O of the acids is 1 to 1.17; that of the O in the clay to the O in the other bases is 1 to 1.71. The slag, therefore, will be readily fusible. Since 100 kilos of pig-iron are produced, Table I. shows at a glance the percentage composition of the product. This pig would not be suited for an air-refining process, but it may easily be converted into refined iron by the refining process presently to be described.

TABLE II.—*Heat-Calculation for the After-Reduction and Melting of Table I.*

No.	Items of Debit and Credit.	Calories Produced.	Calories Consumed.
	Chemical Reactions:		
1	0.439 Fe reduced from $Fe_2O_3 \times 1796$	.....	787
2	0.015 Mn " " $Mn_3O_4 \times 2273$	.....	34
3	2.083 Mn " " $MnO \times 2000$	.....	4,166
4	0.800 Si " " $SiO_2 \times 7830$	.....	6,264
5	0.265 S " " $SO_2 \times 2800$	.....	782
6	0.006 P " " $P_2O_5 \times 5760$	.....	35
	The reduction of Ca from CaO, and its combustion to CaS, balance each other.		
7	0.240 H reduced from $H_2O \times 28,729$	.....	700
8	1.8 C oxidized to $CO_2 \times 8080$	14,544	.....
9	20.142 C " " $CO \times 2473$	49,811	.....
	Hot Blast at 700° *Cent. carries:*		
10	0.900 $H_2O \times 497.7$	448	.....
11	27.472 O $\times$ 157.5	4,326	.....
12	92.032 N $\times$ 180.04	16,569	.....
	Iron Sponge at 1100° *Cent. carries:*		
13	92.779 Kg. Fe $\times$ 1100 $\times$ 0.22	22,452	.....
14	37.511 Kg. of slag-forming components, $\times$ 1100 $\times$ 0.25	10,315	.....
	Molten Product carries off:		
15	100 Kg. pig-iron @ 300 cals.	.....	30 000
16	34.824 Kg. slag @ 500 cals.	.....	17,412
	Gases at 1100° *Cent. carry off:*		
17	0.240 H $\times$ 4,658	.....	1,118
18	6.600 $CO_2 \times 481.8$	.....	3,180
19	139.030 CO + N $\times$ 292.27	.....	40,634
			105,112
	Balance, excess of heat produced (available for losses)		13,353
		118,465	118,465

Table II. shows the thermal calculations for the melting-operation. The greater part of the CO_2 formed by burning the coke is reduced to CO, only a very small portion escaping reduction. The

TABLE III.—*Reduction of Calcined Ore with Gas for a final product of* 100 *Kilogrammes of Pig-Iron.*

Constituents.	Materials Used, Kgs.				Products, Kgs.	
	Calcined Ore.	Reducing Gases from Melting.	Reducing Gases from Recuperating.	Totals.	Iron Sponge.	Waste-Gases.
FeO	39.935	.....	.....	39.935	0.900	.....
Fe_2O_3	89.169	.....	.....	89.169	.....	.....
Fe	.....	.....	.....	.....	92.779	.....
MnO	.....	.....	.....	.....	7.199	.....
Mn_3O_4	7.740	.....	.....	7.740	.....	.....
MgO	3.782	.....	.....	3.782	3.782	.....
CaO	4.673	.....	.....	4.673	4.673	.....
Al_2O_3	4.918	.....	.....	4.918	4.918	.....
SiO_2	16.039	.....	.....	16.039	16.039	.....
CO	.....	46.998	135.943	182.941	.....	120.000
CO_2	.....	6.600	.....	6.600	.....	105.507
H_2O	.....	.....	.....	.....	.....	.....
H	.....	0.240	0.453	0.693	.....	0 693
N	.....	92.032	90.175	182.207	.....	182.207
Total	166.256	145.870	226.571	538.697	130.290	408.407

TABLE IV.—*Heat Calculation for the Gas-Reduction of Table III.*

No.	Items of Debit and Credit.	Calories Produced.	Calories Consumed.
1	The calcined ore at 800° C. carries 166.25 × 0.25 × 800	33,251	.....
2	The melting-gases at 1100° C. carry	44,932	.....
3	The recuperated gases at 700° C. carry:		
	135.943 CO × 180 04 .....Cals. 24.474	.....	.....
	0.453 H × 2880 5 ..... " 1.304	.....	.....
	90.175 N × 180 04..... " 16.236	42,014	.....
4	30.361 Fe reduced from FeO × 1352	.....	41,048
5	62.418 Fe " " Fe_2O_3 × 1796	.....	112.102
6	7.199 MnO " " Mn_3O_4	.....	1,522
7	62.941 CO oxidized to CO_2, by the reduced ore	151.247	
8	The iron sponge at 1100° C. carries off:	.....	32,767
9	The waste-gases at 600° C. carry off:		
	120.000 CO × 153.0.....Cals. 18.360	.....	.....
	105.507 CO_2 × 199.2..... " 21.016	.....	.....
	0.693 H × 2451.0..... " 1,699	.....	.....
	182.207 N × 153.0..... " 27,878	.....	68,953
		.....	256,392
	Balance, excess of heat produced	.....	15,052
		271,444	271,444

TABLE V.—*Calcination of Ore with Gas for a Final Product of 100 Kilogrammes of Pig-Iron.*

Constituents.	Materials Used, Kgs.					Products, Kgs.	
	Spathic Ore.	Clay-Slate.	Waste-Gas from Reduct.	Air.	Totals.	Calcined Ore	Waste-Gases.
FeO	119.804	.....	.....	.....	119.804	39 935	.....
Fe_2O_3	0.146	0.280	.....	.....	0.426	89.169	.....
MnO	7.198	.....	.....	.....	7.198	.....	.....
Mn_3O_4	.....	.....	.....	.....	.....	7.740	.....
MgO	3.782	.....	.....	.....	3.782	3.782	.....
CaO	4.636	0 037	.....	.....	4.673	4.673	.....
Al_2O_3	3.904	1.014	.....	.....	4.918	4.918	.....
SiO_2	10.370	5.669	.....	.....	16.039	16.039	.....
CO	.....	.....	120 000	.....	120.000	.....	125 978
CO_2	83.814	.....	105 507	.....	189 321	.....	179.927
H_2O	10.346	.....	.....	.....	10.346	.....	16.583
H	.....	.....	0.693	.....	0.693	.....	.....
O	.....	.....	.....	11.544	11.544	.....	.....
N	.....	.....	182 207	38.672	220.879	.....	220.879
Total	244.000	7.000	408.407	50.216	709.623	166.256	543.367

TABLE VI.—*Heat Calculation for the Calcination of Table V.*

No.	Items of Debit and Credit.	Calories Produced.	Calories Consumed.
1	The waste-gases from the reduction at 600°, carry.....	68,953	.....
2	Expulsion of 83.814 CO_2 × 110	.....	9,219
3	" " 10 346 H_2O × 540	.....	5,587
4	Oxidation to Fe_2O_3 of 79.869 FeO, equivalent to 62 122 Fe × 444.....	27,582	.....
5	Oxidation to Mn_3O_4 of 7.198 MnO, equivalent to 5.567 Mn × 273.....	1,520	.....
6	Reduction of 16.478 CO from CO_2 × 2,403.....	.....	39,596
7	Oxidation of 10.5 CO to CO_2 × 2.403.....	25,231	.....
8	" " 0.693 H to H_2O × 28,729.....	19,908	.....
9	Calcined Ore at 800° C. carries off.....	.....	33,251
10	Waste-Gases at 200° C. carry off:		
	125.978 CO × 49.3.....Cals. 6.211	.....	.....
	179.927 CO_2 × 48.0..... " 8,636	.....	.....
	16.583 H_2O × 98.6..... " 1.634	.....	.....
	220.879 N × 49.3..... " 10,888	.....	27,369
		.....	115,022
	Balance, excess of heat produced.....	.....	28,172
		143,194	143,194

pyrometric effect is such as to produce the melting of the pig-iron and the formation and fusion of the slag. The calculated temperature is 1650° Cent.

In Table III. the chemical changes attending the gas-reduction of the calcined ore are given. The gases from the melting-operation together with others, rich in CO, from the recuperators, effect the reduction. In treating this spathic ore, it is not necessary, as an examination of Table IV. will show, to burn a portion of the reducing-gas with blast, since the heat of the calcined charge and that of the gas itself are sufficient to cover the entire absorption occasioned

TABLE VII.—*Gas-Refining of* 100 *Kilogrammes of Pig-Iron.*

Constituents.	Materials Used, Kgs.				Products, Kgs.		
	Pig-Iron.	Gas.	Air.	Totals.	Refined Iron.	Waste-Gas.	Cinder.
Fe.	93.218	.....	.....	93.218	92.168	.....	.....
FeO.	.....	.....	.....	.....	.....	.....	0.450
Mn.	2.098	.....	.....	2.098	0.698	.....	.....
MnO	.....	.....	.....	.....	.....	.....	1.808
Si.	0.800	.....	.....	0.800	0.030	.....	.....
SiO_2	.....	.....	.....	.....	.....	.....	1.650
C.	3.858	.....	.....	3.858	0.500	.....	.....
CO	.....	32.365	.....	32.365	.....	.....	.....
CO_2	.....	.....	.....	.....	.....	63.169	.....
S.	0.020	.....	.....	0.020	.....	.....	.....
SO_2	.....	.....	.....	.....	.....	0.040	.....
P.	0.006	.....	.....	0.006	0.006	.....	.....
H.	.....	0.107	.....	0.107	.....	0.107	.....
O.	.....	.....	37.860	37.860	.....	8.706	.....
N.	.....	18.874	126.831	145.705	.....	145.705	.....
Fe_2O_3	.....	.....	.....	.....	.....	1.000	.....
Total	100.000	51.346	164.691	316.037	93.402	218.727	3.908

by the deoxidation. The temperature below the gas-tuyeres will be abont 1100° Cent. At the tuyeres the temperature will drop to about 850° on account of the admixture of recuperated gas at 700°, and higher up in the furnace the temperature will drop still further, to about 600°, owing to the deoxidation. The percentage-composition of the gases at the level of the gas-tuyeres is :

	Per cent. By weight.
CO,	49.1
CO_2	1.8
H,	0.1
N,	49.0

With such a high percentage of CO and low percentage of CO_2, the reduction will proceed very rapidly, all the more so, since in this zone of the furnace the temperature is very favorable for the reaction.

At the upper end of the reducing-zone the gases have the following composition:

	Per cent. By weight.	By volume.
CO,	29.4	31.5
CO_2,	25.8	17.5
H,	0.2	3.0
N,	44.6	48.0

This gas still retains strong reducing-properties.

TABLE VIII.—*Heat Calculation for the Gas-Refining of Table VII.*

No.	Items of Debit and Credit.		Calories Produced.	Calories Consumed.
1	The pig-iron carries into the refining chamber.....		27,700	.....
2	Chemical Reactions:			
	0.700 Fe oxidized to Fe_2O_3 × 1796.....Cals.	1,257	.....	.....
	0.350 Fe " " FeO × 1352..... "	473	.....	.....
	1.400 Mn " " MnO × 2000..... "	2.800	.....	.....
	0.770 Si " " SiO_2 × 7830..... "	6.029	.....	.....
	3.358 C " " CO_2 × 8080..... "	27,132	.....	.....
	0.020 S " " SO_2 × 2000..... "	40	.....	.....
	32.365 CO " " CO_2 × 2403..... "	77,773	115,504	.....
3	93.402 Kgs. refined iron at 1800° carry off.....		.....	41,004
4	3.908 Kgs. cinder carry off.....		.....	2,400
5	1.000 Kgs. Fe_2O_3 dust carries off.....		.....	600
6	Recuperated gas at 700° Cent. carries:			
	32.365 CO × 180.04..... Cals.	5,826	.....	.....
	0.107 H × 2880.5..... "	308	.....	.....
	18.874 N × 180.04..... "	3,397	9,531	.....
7	Hot Blast at 700° Cent. carries:			
	37.860 O × 157.5 .....Cals.	5,963	.....	.....
	126.831 N × 180.04..... "	22.834	28,797	.....
8	Waste-Gases at 1600° Cent. carry off:			
	63.169 CO_2 × 788.0 .....Cals.	49,776	.....	.....
	0.107 H × 7016.0 ..... "	751	.....	.....
	145.705 N × 442.30..... "	64,445	.....	.....
	8.706 O × 386.9 ..... "	3,368	.....	118,340
				162,344
	Balance, excess of heat produced (available for losses)			19,188
			181,532	181,532

TABLE IX.—*Recuperation of the Waste-Gas generated in producing 100 Kilogrammes of Pig-Iron.*

Constituents.	Materials Used, Kgs.			Recuperated Gas Produced, Kgs.
	Waste-Gas from Calcination.	C.	Total.	
CO	58.021	.....	58.021	168.308
CO_2	83.135	.....	83.135	.....
H_2O	5.040	.....	5.040	.....
N	109.049	.....	109.049	109.049
C	.....	22.672	22.672	.....
H	.....	.....	.....	0.560
Total	255.245	22.672	277.917	277.917

TABLE X.—*Heat Calculation for the Gas-Recuperation of Table IX.*

No.	Items of Debit and Credit.	Calories Produced.	Calories Consumed.
1	Waste-Gases from calcination, at 100° C., carry:		
	58.021 CO × 24.43 ..... Cals. 1,417	.....	.....
	83.135 CO_2 × 24.0 ..... " 1,995	.....	.....
	5.040 H_2O × 49.3 ..... " 249	.....	.....
	109.049 N × 24.43 ..... " 2,664	6,325	.....
2	52.904 CO reduced from CO_2 × 2,403	.....	127,129
3	0.560 H " " H_2O × 28,729	.....	16,088
4	22.672 C oxidized to CO × 2,473	55,068	.....
5	Recuperated gas at 900° C., carries off:		
	168.308 CO × 235.35 ..... Cals. 39,611	.....	.....
	109.049 N × 235.35 ..... " 25,664	.....	.....
	0.560 H × 3757.5 ..... " 2,104	.....	67,379
		61,393	.....
	Balance, deficit of heat produced	149,203	.....
		210,596	210,596

Through the tuyeres D, cold blast is admitted to the calcining-chamber to burn a portion of the CO and all the H contained in the gases from the reducing-chamber. Since the products of this combustion contain no excess of free O, the calcination will proceed as it would in the absence of air, according to the formula:

$$3FeCO_3 = Fe_3O_4 + 2CO_2 + CO,$$

by which a part of the CO_2 is reduced and eliminated as CO. Table V. shows the chemical history of the calcination, and Table VI. the heat-equation of the same. In the upper part of the calcining-chamber the charge is dried and preheated by the ascending gases, which, on leaving the furnace, have the following composition:

	Per cent. By weight.	By volume.
CO,	23.2	25.6
CO_2,	33.1	23.2
H_2O,	3.0	6.5
N,	40 7	44.7

These gases are still fairly combustible; indeed, the waste-gases of charcoal-furnaces rarely contain more CO. Since the charge consists of uncalcined ore, there will be but little flue-dust. The waste-gases go in part to the recuperator, to be enriched and utilized for further ore-reduction and refining, and in part they are burnt in the Whitwell stoves.

The enriching action of the recuperator appears in Table IX., and the corresponding heat-equation in Table X., according to which about 37.5 per cent. of the calcining-gases go to the recuperator and require 22.672 C for complete saturation. The heat-equation shows

TABLE XI.—*Heating of the Recuperator after the Heat-Absorption of Tables IX and X.*

Constituents.	Materials Used, Kgs.			Products, Kgs.	
	Lignite.	Air.	Total.	Burnt Gases.	Residue.
CH_4	0.518	.....	0.518	.....	.....
C	48.301	.....	48.301	.....	32.254
N	0.375	206.250	206.625	20 .625	.....
H	1.746	.....	1.746	.....	.....
O	.....	61.500	61.500	9.068	.....
H_2O	19.980	.....	19.980	36.855	.....
Ash	4.080	.....	4.0 0	.....	4.080
CO	.....	.....	... .	6.527	.....
CO_2	.....	.....	.....	47.341	.....
Total	75.000	267.750	342.750	306.416	36.334

that 149,203 calories must be taken from the fuel in the recuperator and from the gas-heater, in order to cover the absorption due to the recuperation. Table XI. and the accompanying heat-computations, Table XII., show, that by burning 75 kilograms of lignitic coal

TABLE XII.—*Heat Calculation for Table XI.*

No.	Items of Debit and Credit.			Calories Produced.	Calories Consumed.
1	Combustion of 0.518 CH_4	× 13,063 ..... Cals.	6,767	.....	.....
	" " 13.250 C	× 8,080 ..... "	107.060	.....	.....
	"(to CO)" 2.797 C	× 2,473 ..... "	6 917	.....	.....
	" " 1.746 H	× 28,729 ..... "	50,160	170,004	.....
2	Hot Blast at 700° C. carries:				
	61.500 O	× 157.5 ..... Cals.	9,686	.....	.....
	206.250 N	× 180.04 ..... "	37,133	46,819	.....
3	Burnt Gases at 300° C. carry off:				
	47.341 CO_2	× 86.4 ..... Cals.	4,090	.....	.....
	213 152 CO + N	× 74.58 ..... "	15,897	.....	.....
	9.068 O	× 65.25 ..... "	591	.....	.....
	36.855 H_2O	× 169.5 ..... "	6,235	.....	.....
	19.980 H_2O	× 536.0 ..... "	10,709	.....	37,522
	Residue after one heating and recuperating operation, at 600° Cent., 23.662 × 0.25 × 600			.....	3,550
	22.672 Kgs. C., and the checker-work heater (see tables IX. and X.) carry			.....	149,203
					190,275
	Balance, excess of heat produced			.....	27,448
				217,723	217,723

with blast at 700° Cent., the requisite heat for recuperation, may be generated, allowing 27,448 calories, or 12 6 per cent. of the total heat so produced to be consumed by radiation. Lignite, of the kind here assumed, occurs in the vicinity of the Styrian iron-ore, and contains:

	Per cent.
CH_4,	0.690
C,	64.402
N,	0.500
H,	2.328
H_2O,	26.640
Ash,	5.440

The recuperating-process is supposed to take place in the following manner: A recuperator, cooled by a preceding recuperation, is filled with a proper amount of lignite, and a hot, high-pressure blast is then introduced at several levels, so that an excess of O prevails in all zones of the fire, as a result of which the combustion is very

TABLE XIII.—*Calculation for Heating the Blast required for the Production of* 100 *Kilogrammes of Pig-Iron.*

No.	Items of Debit and Credit.	Calories Produced.	Calories Consumed
1	Waste-Gases from calcination, at 80° C., carry:		
	96.792 CO_2 × 0.2074 × 80.....Cals. 1,605	.....	.....
	67.957 CO × 0.2439 × 80..... " 1,326	.....	.....
	11.543 H_2O × 0.4363 × 80..... " 403	.....	.....
	111.830 N × 0.2439 × 80..... " 2,181	5,515	.....
2	Combustion of 67.957 CO × 2403.....	163,301	.....
3	The burnt gas, at 300° C., carries off:		
	203.581 CO_2 × 86.4 .....Cals. 17,588	.....	.....
	9.168 O × 65.25..... " 598	.....	.....
	11.543 H_2O × 169.5 ..... " 1,955	.....	.....
	272.630 N × 74.58..... " 20,332	.....	40,473
4	Heating the Blast to 800° Cent.:		
	126.832 O × 181.49.....Cals. 23,018	.....	.....
	425.113 N × 430.44..... " 88,185	.....	111,203
			151,676
	Balance, excess of heat produced (available for losses)	.....	17,140
		168,816	168,816

complete. Any CO escaping from the fuel-bed is burnt with blast admitted above the fire. The products of combustion surrender their waste-heat to fire-brick checker-work in one of the gas-heaters, and then escape to the stack at a temperature of 300° Cent. In this combustion, all the hydrocarbons and some of the fixed carbon are burned, leaving only C and ash in the recuperator. When a proper temperature has been attained in the recuperator and the gas-heater, the waste furnace-gas is passed through the latter into the former, thus reaching the incandescent fuel in a highly heated condition, in which it takes up an amount of C proportionate to its content of CO_2, and then leaves the recuperator at a temperature averaging 900° C. After the recuperator has cooled down to a point where the temperature is no longer sufficient for the reaction, the valves are shut, the ashes drawn, and a fresh lot of fuel is charged. In calculating the thermal equation for heating the recuperator (Table XII.), it is assumed that 9.582 kilogrammes, or nearly 20 per cent. of the C in the fuel remains unconsumed in the ash. A portion of the recuperated gas goes to the reducing-chamber and the rest to the refining-chamber.

TABLE XIV.—*Thermal Balance-Sheet for the production of* 100 *Kilogrammes of Pig-Iron.*

HEAT PRODUCTION.	Calories.	Calories.	Per Ct.
Coke, 25.300 C burned to CO_2 × 8080	204.424	.....	.....
Lignite, 0.518 CH_4 burned to CO_2 and H_2O × 13,063	6,767	.....	.....
38.719 C burned to CO_2 × 8080	312,848	.....	.....
1.746 H burned to H_2O × 28,729	50,160	.....	.....
	574,199		
HEAT CONSUMPTION.			
93.402 kgs. refined iron	.....	41,004	7.14
3.908 " refinery cinder	.....	2,400	0.42
1.000 " Fe_2O_3 dust	.....	600	0.10
34.824 " slag after melting	.....	17,412	3.03
0.037 " Fe from Fe_2O_3 × 1796 66	.....	.....	.....
92.131 " Fe from FeO × 1352 124,561	.....	.....	.....
0.015 " Mn " Mn_3O_4 × 2273 34	.....	.....	.....
0.683 " Mn " MnO × 2000 1,366	.....	.....	.....
0.030 " Si " SiO_2 × 7830 235	.....	.....	.....
0.006 " P " P_2O_5 × 5760 35	.....	.....	.....
0.265 " S " SO_3 × 2800 782	.....	127,079	22.13
Losses in the gas-flues: Between the recuperator and the reducing- and refining-chambers, 67,379—51,545 15,834	.....	.....	.....
Between the calcining-chamber and the recuperator and hot-blast stove, 27,369—11,840 15,529	.....	31,363	5.47
Losses in the hot-blast pipes, 111,203—96,959	.....	14,244	2.48
Carried off in waste-gases:			
From refining 118,340	.....	.....	.....
" heating the blast 40,473	.....	.....	.....
" recuperating 37,522	.....	196,335	34.19
Carried off in the recuperator residue	.....	3,550	0.62
Losses from radiation, etc.:			
In melting 13,353	.....	.....	.....
" deoxidizing 15,052	.....	.....	.....
" calcining 28,172	.....	.....	.....
" refining 19,188	.....	.....	.....
" recuperating 27,448	.....	.....	.....
" heating the blast 17,140	.....	.....	.....
" sundries (by difference) 19,859	.....	140,212	24.42
		574,199	100.00

Table VII. shows the chemical history of the refining, this action being carried so far, in our assumed case, that the product may be converted into ingot-metal (mild steel) in the shortest possible time by treatment in an open-hearth furnace. If the refined metal is to

be converted into weld-iron in a puddling-furnace, the decarburization should not be carried quite so far; the extent to which the action is carried can be perfectly controlled by turning on a greater or less excess of blast during the operation. The theoretical calculation in Table VIII. shows that heat enough is generated to refine the pig-metal and maintain the product at a sufficiently high temperature.

By tracing the course of the gases which are not recuperated, we reach the hot-blast stoves, which are assumed to be of the fire-brick type. The heat-computation is shown in Table XIII., according to which the non-recuperated portion of the furnace-gas suffices to heat all the blast required for the melting, recuperating and refining. The final result of the whole calculation is, that 100 kilogrammes of pig-metal, or 93.402 kilogrammes of refined iron can be produced from the given ore with a consumption of 30 kilogrammes of coke and 75 kilogrammes of lignitic coal, the waste-gases sufficing to preheat the blast. Beyond this fuel-consumption, therefore, we have to take account only of the power-requirements. If water-power is not available, economical steam-engines will be used for actuating the blowing-engines, stock-hoist, pumps, etc., an allowance of 20 to 25 kilogrammes of lignite being made for that purpose.

It remains for us to strike a thermal balance-sheet for the entire process, in order to show that all possible losses have been duly considered, and that we have not been too sanguine in our statements. Table XIV. gives a summary of the entire heat-movement. Since carbon and hydrogen occur in the waste-gases only in the form of CO_2 and H_2O, all C not contained in the refined iron or in residual ash is figured to CO_2, and all H of the lignite is figured to H_2O. It is seen that of the total heat generated, 22.13 per cent. is used for the reduction, and 7.14 per cent. for heating the final product; 3.55 per cent. is absorbed by the liquid by-products and flue-dust, and 0.62 per cent. is lost as unconsumed carbon in the recuperator-ash. The products of combustion carry off 34.19 per cent., a portion of which, contained in the refinery-gases, may be utilized for other purposes. For losses by radiation, 5.47 per cent. is charged to the gas-flues, 2.48 per cent. to the hot-blast flues, and 24.42 per cent. of the total heat-production is allowed for radiation from the exterior furnace-walls, heat carried off in the cooling-water, and sundry other losses.

THE MICROSTRUCTURE OF INGOT-IRON IN CAST INGOTS.

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(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

INTRODUCTION.

WHEN I was honored with an invitation from the American Institute of Mining Engineers to present a paper at the Chicago meeting on the microstructure of iron, I hesitated about accepting, as the short interval that would remain at my disposal, after other pressing matters had received attention, could not but seriously affect the work of preparing such a paper. Unfortunately my fears have been realized and my work is neither completed, nor yet as comprehensive as I should desire. Mindful of my promise, however, and recognizing that I have reached a point where the results of my researches may prove suggestive, I am led to present them now, trusting that this brief explanation may secure indulgence for whatever deficiencies the paper may disclose.

So far as my knowledge of published memoirs and treatises extends, microscopy cannot yet be said to possess a really firm foundation. In few cases only has any systematic development of the methods of investigation been undertaken, and broad gaps remain to be filled. It is not yet possible, therefore, to give a complete survey of the field, or, indeed, to supply a text-book on microscopic metallography. As Mr. F. Osmond, of Paris, a distinguished member of our profession, has undertaken to prepare for the Chicago meeting a historic review of the work actually accomplished I need not touch on that branch of the subject; but before entering upon my special theme, it may not be out of place for me to introduce certain explanations, as furnishing reasons for the course I have hitherto pursued, and to offer some suggestions for the further development of the methods of microscopic investigation.

In microscopic metallography, the examination has to be conducted principally with incident light. Objectives of low power, in which the distance between the front lens and the object is considerable, are adapted for directly incident light, and in such cases the relatively great depth of the image renders it possible to examine

* Translated by W. B. Kunhardt, New York City.

comparatively uneven surfaces of fracture. As a rule, however, the microscope is restricted to the examination of plane surfaces, or of those in which the elements are in exceedingly low relief. In proportion as higher magnifying powers are required to resolve the elements, stronger objectives become necessary; the depth of the image is lessened; the working-distance from the object-glass to the stage has to be reduced, and the difficulties of the examination are correspondingly increased. These are the conditions governing all methods applicable to the microscopic resolution of the structural elements of the object.

The first requisite is illumination from above, that is to say, incident light. With objectives of low power and ample working-distance, it may be obtained by inclining the objective until the incident ray is reflected into the tube of the instrument from an opaque mirror attached at the side, or from a thin transparent mirror-plate mounted at an angle of forty-five degrees in front of the object-glass. A total-reflecting prism, covering one-half the aperture of the object-glass, may be substituted for this second form of mirror. In using an objective of higher power, these accessories must be attached above it, so that the light shall pass through it (or through the whole system of lenses of the instrument) and fall upon the object. With such a method of illumination, it becomes practicable to employ objectives of very high power.

The microscopist's art, which may be defined as the resolution of an object to microscopic apprehension, adapts two kinds of means—first, modifications in the manner of illuminating, which include the supply of light from the side; examination in reflected light by inclining the object, or vertical illumination upon the object; use of colored light, especially in photography, etc.: second, artificial changes in the object itself, whereby one of its elements may be made to appear so characteristically altered that from the nature of the altered state definite conclusions regarding the nature and properties of the particular element may be drawn. These artificial influences may be physical or chemical. They either alter the appearance of the object (coloration methods), or remove certain particles of the body (etching methods), or form new coatings over certain of the structural elements (precipitation methods, such as coloration with Prussian blue, galvanic coatings, etc.). The greater the number of methods for effecting a characteristic alteration of each structural element, and of distinguishing it from all other elements, the more positive will be the microscopic determination of that element, and

the more assured will become the practical utility of microscopic metallography.

The development of methods of the first kind is easy and has often been attempted; indeed, excellent progress has been made, but further systematic work is required. On the other hand, the development of methods of the second kind is far more difficult, and much diligent and patient labor will be required of many investigators, before microscopic metallography can be raised to the same practical level in metallurgy that chemistry now occupies. That this plane will, indeed, be reached, no one can doubt, who himself has carried on these researches, or ever has had the opportunity to study a good collection of metal-sections. As the complement of chemical analysis and mechanical tests, microscopy will afford us a deep insight into the constitution of the metal, and serve particularly to render the results of chemical analysis more intelligible. It is obvious that the second class of methods for the resolution of the object constitutes nothing less than a special mode of conducting chemical analysis—a system of microchemistry as it has been called. Microchemical analysis differs from the ordinary chemical examination in that it undertakes to determine the chemical composition of the several, microscopically separable, elements of structure of the body, whereas the usual chemical analysis determines only the average composition of all the elements of structure, except in cases where, by chemical means, a subdivision into groups is first effected. Such cases are exceptional, yet in microchemistry analogous subdivisions should not be neglected. Through impatient zeal, some investigators have been led to attempt, with the aid of well-known yet defective methods, to obtain the much-desired insight into the relations of structural elements—such, for example, as are exhibited in iron of various kinds, or under different treatments. Personally I pursued this course only to penetrate deeper into the subject of my investigation. The true aim, however, to be steadily and earnestly kept in view, is first to develop the methods for the microscopic resolution of the elements of structure and to determine their chemical composition. So far as one who is not a chemist may, I have never lost sight of this aim, and as I perceived that it lay beyond the reach of my unaided powers, I have repeatedly endeavored to interest men of better qualifications in its pursuit. At present I believe there is a prospect that the *Königliche Mechanisch-Technische Versuchsanstalt zu Charlottenburg*, which has been placed under my direction, will be equipped through the liberality of the Govern-

ment with a special microscopical laboratory and with means for securing the co-operation of competent coadjutors. To all friends of microscopic metallography, however, I now appeal, that they pursue their labors along the course I have indicated; it offers the most important point of departure in this field of research.

The separation of the structural elements by coloration may be variously accomplished; as, for example, by producing tarnishes through the gradual heating of the object. In the case of iron and other metals, the intensity of the coloration, and the contrasts between the tints of adjoining elements frequently differ with slight variations in the procedure and the preparation of the piece. The experimenter who would assure himself of the best results, should therefore carefully note and study all secondary details—slow and rapid heating, and heating in successive stages should be tried, with a close examination at each step for any signs of structural modification.

Etching is usually accompanied by alterations of color, either because certain colored elements in a component of the surface are insoluble in the etching-fluid and, by remaining undisturbed, color the entire component in that surface; or because compounds are formed between the loosened particles and the etching-fluid, which, on account of their insolubility in the fluid, adhere more or less firmly at the point where they originate. The attempt will frequently be made to fix these colored coatings artificially, either by making such additions to the etching-reagent as will promote the adhesion of the coloring particles, or by carefully transferring the object from one bath to another, the last always displacing the solution of the preceding one and preparing the object for the next, until finally a solution is reached in which the fixative for the colored coating is precipitated. By such successive immersions one may pass, for example, from water through alcohol and ether to a solution of Canada balsam in chloroform; and, upon the evaporation of the latter, a thin film of the Canada balsam fastens the pulverulent colored precipitate. If the etching-reagent produces colored compounds soluble in water, and on that account the attempt fails to color the particles of the object from which those compounds are derived, experiments should be made with the same reagent in other solutions, such as alcohol, ether, benzine, etc. Reagents like chlorhydric acid, which in themselves produce no color, but merely separate the more soluble from the less soluble constituents, seem to act otherwise in an aqueous solution than in a mixture of ether and alcohol, or in pure ether. At least, it has been my frequent experience to obtain

etchings exhibiting far richer contrasts from solutions of chlorhydric or nitric acid in ether-alcohol than in water. The character, indeed, and the outlines of the resulting figures were the same; but whether this will always be so, remains to be ascertained, for in many cases the character of the figures depends intimately on the mode of etching. An apt illustration is furnished by the use of chlorhydric acid dissolved in ether. Small drops of a viscous fluid form and settle on the section at regular distances, preventing any etching beneath them, though not interfering with the action all around them. The structure apparently developed under such conditions is shown on Plate I., Figs. 1 and 2. The square spots in Fig. 3 show the effect of a deposition of crystals on a section. Such accidental phenomena do not mislead a cautious microscopist, but far greater dangers threaten the unwary or the imaginative observer.*

Chemical analysis may be variously applied to the microscopic investigation of the metals. It may be used to classify substances from a certain point of view: thus, if it be desired to ascertain the effect of a certain admixture of manganese, silicon, sulphur or phosphorus on the structure of carbon-iron, different test-series can be prepared, in which the successive members contain increasing proportions of any of these ingredients, and their sections can be studied.† Microchemistry proper, however, should set itself the task of isolating a certain element of the structure and determining its composition by microchemical means, such as crystallizing the element out of solution and determining the crystals, or a chemical reaction in the microscopic field.‡ The isolation may be effected by boring a fine hole through the glass cover which is cemented to the section with balsam, so as to penetrate to the particular element, and extracting by means of an appropriate solvent a sufficient quantity to determine its chemical composition. Another way is to prepare exceedingly thin plates and treat them with one of the etching-acids ordinarily employed, and thereby separate the more soluble from the less soluble portion, the latter retaining its original form. The solution and residue are then separately tested. The same object is frequently

* See the author's paper on "Das Gefüge der Schienenköpfe." *Stahl und Eisen*, 1892, pp. 406 *et seq.*

† The exhibit of the Experimental Station in the German engineering section of the International Exposition at Chicago contains micro-photographs of a number of such series.

‡ The microscopic study of rocks furnishes familiar examples. See also *Mikroskopische Reactionen*, by Dr. K. Haushofer; published by Vieweg und Sohn, Braunschweig, Germany.

attained by reducing the substance to fine powder before treatment. By prolonged action of the solvent, a comparatively thick piece may sometimes be disintegrated into its separate structural components. Thus I have succeeded in resolving some pieces of spiegeleisen into their crystal-elements (thin columnar tablets), by subjecting them for months to the action of highly diluted chlorhydric acid.* In polished sections, the uppermost layers become disintegrated in shorter time (see Plate I., Fig. 5). Microchemistry, however, is not restricted to wet methods; experimentation with pyro-reactions is, indeed, equally admissible.

In my published memoirs on the microstructure of iron, I have treated first, the structure of gray pig-iron;† next that of white pig-iron on surfaces of fracture and in prepared sections;‡ and last that of fractured wrought-iron.§ In pursuance of my original plan, I propose to consider now the structure of prepared sections of cast ingot-metal, both soft and hard. Incidentally I would mention having on a former occasion touched on rolled ingot-metal, when for certain reasons I deviated from my programme to discuss the structure of a rail-end in a special paper already cited, entitled *Das Gefüge der Schienenköpfe.*

Treatment of Samples.

For my present investigation I have used pieces broken from ingots placed at my disposal in 1883 by the *Bochumer Verein für Gussstahlfabrication.* These ingots were marked by the works as follows:

	Per cent.
Ingot A, Bessemer, medium hard, ...	C = 0.32
Ingot B, Bessemer, hard, ...	C = 0.4
Ingot C, Bessemer, very hard, ...	C = 0.5
Ingot D, Thomas (basic Bessemer), soft, ...	C = 0.06
Ingot E, Thomas (basic Bessemer), medium hard, . .	C = 0.25
Ingot F, Martin (open-hearth), soft (wire), . . .	C = 0.1
Ingot G, Martin (open-hearth), soft, ...	C = 0.25
Ingot H, Martin (open-hearth) medium hard, . . .	C = 0.45

* "Zur Mikrostructur des Spiegeleisens." *Zeitschrift des Vereins Deutscher Ingenieure*, 1878, p. 484.

† "Ueber das Mikroskopische Gefüge und die Krystallisationen des Roheisens' speciell des grauen Eisens." *Ibid.*, 1880, p. 397.

‡ "Zur Mikrostructur des Spiegeleisens." *Ibid.*, 1878, pp. 205 and 481.

§ "Ueber das Kleingefüge des schmiedbaren Eisens, besonders des Stahles." *Stahl und Eisen*, 1887, p. 235 *et. seq.*

The surface of fracture of each of these blocks was cut off cold, with a circular saw, in as thin a plate as possible, and after each plate another was cut off in the same way, several millimeters thick. These plates were quartered, each part representing one-fourth of the cross-section of its respective ingot. One part of each plate was then finely ground and polished, and etched with an ether-alcohol solution of nitric acid. The structure of the ingot appeared very distinctly, in forms generally radiating toward the cooling side. These etched quarter-plates were photographed in three-fourths their natural size and placed beside photographs of the corresponding surfaces of fractures, each taken in half size and representing somewhat more than one-fourth the cross-section of the ingot (Plates II., III. and IV.).* Another quarter-plate from each set was cut into seven strips, 7 to 10 millimeters wide, numbered consecutively from the middle to the side of the ingot, and stamped with the mark of the plate. In every case these marks were stamped near that end of the strip which formed part of the side of the ingot, and which in the photographs is the upper end. All like-numbered strips of the plates A to H were treated alike:

Strips No. 1 were not touched.

Strips No. 2 were heated white-hot at one end, and then plunged into water.

Strips No. 3 were likewise heated white-hot at one end, and then cooled very slowly in charcoal-dust.

Strips No. 4 were heated to a bright-red, plunged into water and then heated from one end, until the heat of that end was incipient red, whereupon the strips were again quenched in water.

In heating, all like-numbered strips were bound together with wire. In the case of sets 2 and 3, the unstamped ends were heated in a forge-fire, with care that the stamped ends, held by the tongs, should be heated as little as possible. In the case of set No. 4, the second heating was also performed while holding the stamped ends with tongs; when the other ends had reached incipient redness, and the pieces were again chilled in water, they showed the following results:

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* In order to reproduce the author's photographic plates for the pages of the *Transactions*, the dimensions of Plates I. to XIII. have been reduced one-half, and of Plate XIV. one-fourth. The magnifying powers given by the author in the text and on the plates have everywhere been reduced to those actually shown in the printed illustrations.—R. W. R.

TABLE I.—*Distances of the Tarnishes from the Stamped Ends of the Strips, or Sides of the Respective Ingots.*

Marks of the Ingots from which test-strips No. 4 are derived.	A	B	C	D	E	F	G	H
Beginning of blue zone, in mm. from stamped end of strip, . . .	27	26	31	24*	29†	24	27	27
End of yellow zone, in mm. from stamped end of strip, . . .	34	34	37	32	33	34	37	36

Strips No. 5 were forged cold, for half their length, and Nos. 6 were forged hot, the stamped end in each case suffering as little change as possible. Lack of time unfortunately prevented the further treatment and examination of these strips, and I am therefore reluctantly obliged to defer the consideration of them.

After the treatment of the first four sets, as described, each set was so arranged and cemented in a grinding-pan, with numbered sides down, that the hard and soft ends of the strips were placed side by side in alternation, this precaution being necessary to secure uniform grinding. The surfaces were then finely ground and well polished. To save time, perfect finish was not insisted on, and therefore a few markings in the micro-photographs will have to be overlooked. These scratches, by the way, mar only the appearance of the surfaces; indeed, for purposes of investigation and interpretation they sometimes prove very useful.

My plan was to etch all the strips in precisely the same way, and I began with a solution of chlorhydric acid in ether-alcohol. But as time advanced apace, I sought to hurry the work by dispensing with the careful removal of the wax-cement, and immediately after polishing the strips of set No. 1 on a damp backing and thoroughly rinsing and brushing them under water, I etched all members of the set together in an aqueous solution of chlorhydric acid. The cement still adhered to the pieces, and all display a reddish-blue tinge, apparently covered with yellowish patches, and sharply relieved by a more or less colorless veining. Probably the wax-cement has played some part here, for never before have I observed such intense coloring as the result of etching with aqueous chlorhydric acid.

After etching, each set of four strips was photographed in one-half

* Indistinct. † Narrow.

size, an operation attended with no small difficulties, as all the strips must reflect light in the same direction if the result of the etching is to be clearly shown. Single sections offer no such difficulty, and in order to overcome it for the several strips, and secure tolerably useful photographs, I devised a special stand for their support, by means of which every possible adjustment toward the incident light could be obtained. The eight sets of strips A, B, C, D, E, F, G, H, four to each set, are represented on Plates II., III. and IV. Next, six micro-photographs of each strip magnified 9.5 to 10 diameters, were taken with an apparatus of my own design,* made by the well-known firm of Karl Zeiss in Jena.

My object was to photograph similarly-located parts of the several strips, regardless whether each particular part happened to be specially suited to make a good picture. On this account I paid little attention to flaws from imperfect polishing (scratches), and for the same reason, in providing for the illumination of the object and in choosing the sensitive plates, I had no thought of securing the most perfect photographs. I always used the orthochromatic plates of Perutz in Munich, without a light-filter, but inserted a ground-glass disk in the iris-diaphragm of the prism. The source of light was a surface of zircon, heated to incandescence in a gas-oxygen flame.† The image of the zircon was sharply delineated upon the disk, the latter being so adjusted that the texture of the glass all but appeared in the object. An extraordinarily effective illumination is thus obtained, and contrasts in the elements of the surface of the object are distinctly defined. But in order to show also the depths and heights of the etching or of pores, I shifted and turned the illuminating-prism just out of center of the field, thus illuminating the object with slightly oblique light, which was reflected back into the tube of the microscope by giving a very slight corresponding inclination to the object. By this artifice the edges of all depressions and elevations appear with strongly accentuated borders of light and shade, wherever the etching has produced a sharp separation of the elements of the surface, or where the deeper scratches occur; many of the latter are thereby easily recognized in the pictures. Thus, from appearances, one can readily judge which of two surfaces lies higher;

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* The apparatus as well as the process are fully described in *Mittheilungen aus den königlichen technischen Versuchsanstalten*, volume for 1891, p. 278, published by Julius Springer, Berlin.

† Koch's zircon-lamp is apparently here referred to by the author.—R. W. R.

that is to say, whether a particular element of the surface has been more or less acted upon by the acid than another. In the vertical scratches the shadow is seen to the right, and the line of high light to the left. All surfaces, therefore, which have dark edges at the right and light edges at the left side are depressions in the object; and all surfaces bordered by light edges on the right and dark ones on the left are elevations.

No retouching of the negatives or positives has been undertaken, nor yet any intensifying or moderating; the condition of the plates has been preserved just as it was after the developing and fixing. Where, however, the exposure had not been timed with sufficient accuracy to produce equally strong negatives, a slight regard for appearances has been exercised by controlling the photographic printing to the extent that the pictures of each series should have, as far as possible, the same general shade. In carrying out this idea, it has been necessary to have some of the positives printed separately. Although as photographs, therefore, the pictures are not the best that might have been made, yet we hope they may represent, as clearly as photographs can, the alterations which the structure of the strips has undergone in the above-described treatment. But as little as these general pictures, magnified 9.5 to 10 diameters, are in every case photographically perfect, just so little also do they completely represent all that the microscopic image of some of the objects can reveal. From among the specially valuable and well-etched sections, therefore, I have taken a series of views with larger magnifying powers, having particular regard for every condition that might exert a favorable influence on the photographs (Plates I., III. and XIII.). Unfortunately, the time at my disposal was inadequate to extend this portion of the investigation as far as would have been desirable.

The figures on Plates V. to XII. are arranged in the following manner: Beginning at the left end of the upper row, they are numbered consecutively from *a* to *f*; these letters apply also to the three rows below the upper one, and signify that the figures designated by the same letter represent similarly located parts of the strips, their positions being shown by the corresponding small letters to the right in the pictures of the strips (Plates II., III. and IV.).

The distances from the side of the ingot to the parts marked by the different letters, each part being taken approximately from the longitudinal center-line of its respective strip, are:

	Millimeters.
For *a*,	60–55
For *b*,	50
For *c*,	40
For *d*,	30
For *e*,	20
For *f*,	10

With this system of marking it becomes practicable to select for chemical analysis precisely that part of the object which has been photographed. I have been obliged, however, to defer the chemical investigation, it having been evident from the beginning that the available time would barely suffice for the microscopic portion of the work, as, without my own laboratory, I am obliged to depend upon the co-operation of friends, to whom, however, I can deliver the sections only after the microscopic work has been completed.

Each individual figure on Plates V. to XII. corresponds lengthwise with the longitudinal axis of the strip, so that an idea of their true relative position in the strip may be obtained by imagining the arrangement of each set of figures *a* to *f* in a series one below the other. The left-hand figures on Plates V. to XII. represent the highly heated or the tempered ends of the several strips.

A general comparison of the sections, Plates V. to XII., shows a similarity in the structure of cast Bessemer ingot-metal (Plates V., VI., VII.), in the three samples, one on each plate, which were treated alike. A similarity is also to be observed in the character of the two samples of Thomas ingot-metal (Plates VIII. and IX.), and likewise between the three samples of open-hearth ingot-metal (Plates X., XI. and XII.). The marked effect produced upon the metal by the different modes of treatment will also be recognized at a glance.*

In the following pages I shall use the terms Bessemer, Thomas (basic converter), and open-hearth metal, without reference to the softness or hardness of the material, but always with the understanding that only cast material, which has not been mechanically worked, is meant, unless an exception is specially mentioned. I desire to state expressly, that my descriptions are to be drawn chiefly from the microscopic subjects themselves, for, in all cases, and particularly under the governing conditions which I have explained, photography reproduces only a weak stereotype of the true image, and

* I desire to call attention to F. Osmond's remarks upon this subject in his report *Sur la Metallographie Microscopique*, prepared for the "Commission des Méthodes d'Essai des Matériaux de Construction."

loses many of its details.* I should have added colored drawings, if my time-limitations had allowed it, and if the cost of printing would not have been very much increased. Under the circumstances, the photographs will serve only to aid in conveying a pictured impression of my words.

Description of Sections.

Bessemer Samples, No. 1.—For a detailed description of the microscopic structure of cast ingot-metal, I shall restrict myself for the present to the Bessemer metal shown on Plates V., VI., VII. As previously mentioned, the several test-strips, No. 1, were etched in a highly diluted aqueous solution of chlorhydric acid. The two strips, No. 1, representing ingots A and B (Plates V. and VI., top rows) display bright, faintly yellow figures, embedded in sharply-defined, deep-blue to reddish surfaces. In the sample of ingot C (Plate VII., top row) the ground is blue only in places and spots. On the whole, this sample shows lighter shades of color than A and B, and for that reason presents no such sharp contrasts in the structure. The photographs of samples A and B would have been improved by the use of a light-filter. I have already suggested that the intense blue coloration may have been due to the wax-cement, consisting of one-half beeswax and one-half turpentine-resin, which still adhered to the samples, and of which certain constituents may have been dissolved in minute quantities. This question, however, requires a thorough investigation, which possibly may result in the skilful utilization of the causes whatever they may prove to be.

If the ground plates and the surfaces of fracture of Plate II. are compared with the sections shown in Plates V., VI., and VII., it is seen that the elongated, rudimentary crystals (or bacillary structure), developed at right angles to the cooling surfaces, are distinctly repeated in the polished sections (in Figs. B_1, B_3, and C_3, as bright, and in C_1 as dark border-lines). In the planes of the sections, these bacilla or slender rods are covered with numerous bright, more or less regularly disposed and often parallel stripes, or with bright

* This remark applies especially to the illustrations accompanying the present paper, by reason of the reduction of scale which they have suffered in publication, as explained by the Secretary's foot-note on page 43. The reproduction in print is excellent—as good as could be effected by the process employed. But the fine network of lines on the photographs would necessarily lose part of its details in such reproduction, even on the same scale, and the loss is considerably greater under a reduction to one-half. Of the finer details mentioned in the text, the reader will therefore sometimes find no indication left in the engravings—a deficiency which he is requested to excuse.

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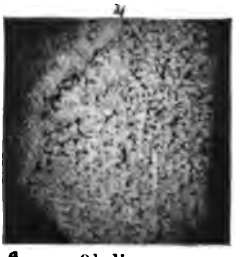
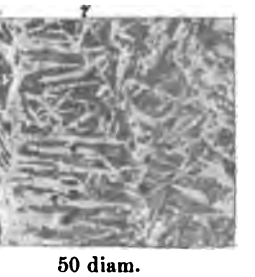


$\mathfrak{C}$ 9½ diam.



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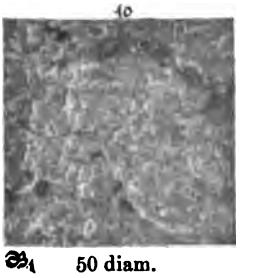
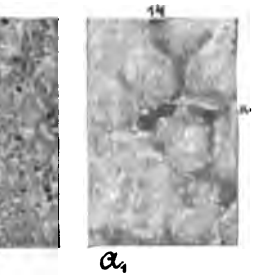


$\mathfrak{B}_1$ 50 diam.



$\mathfrak{A}_1$

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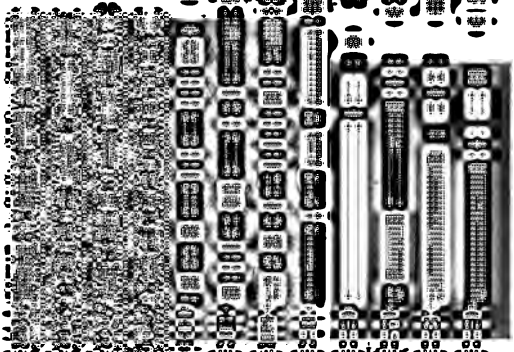

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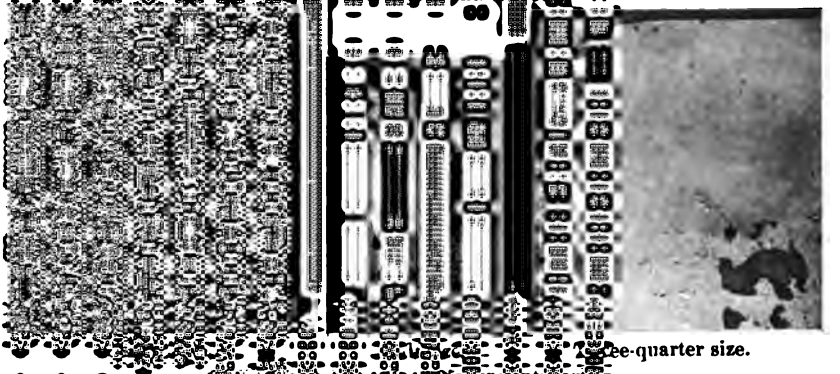

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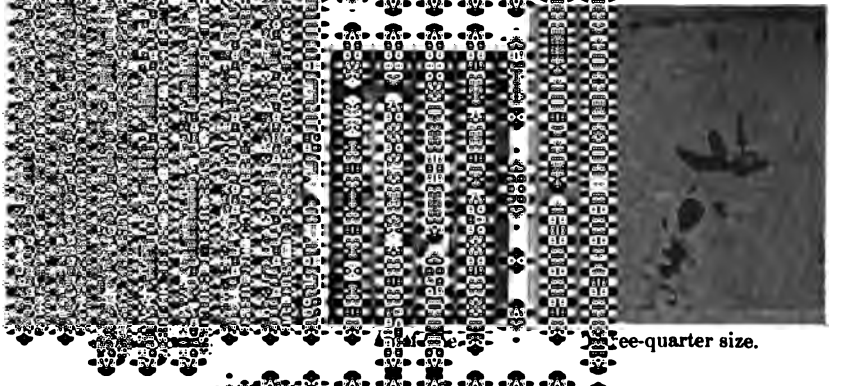

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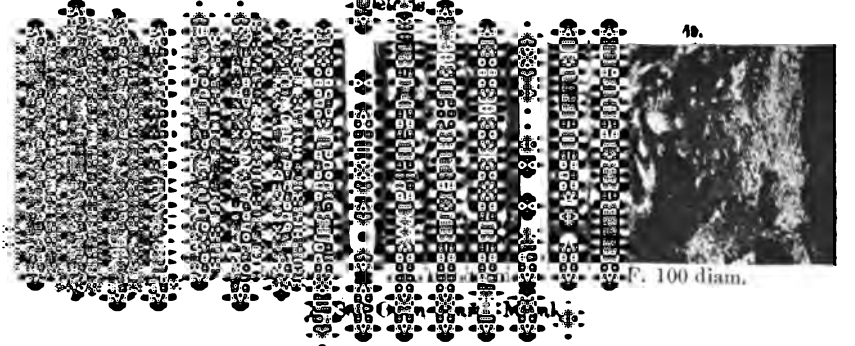

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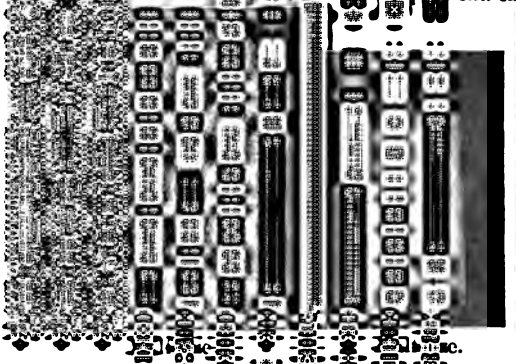

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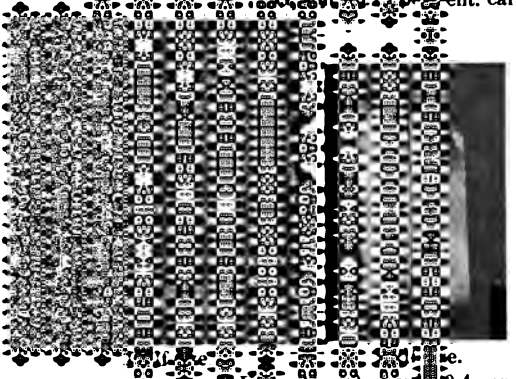

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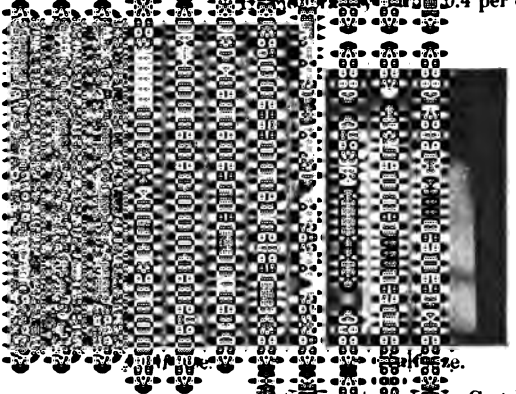

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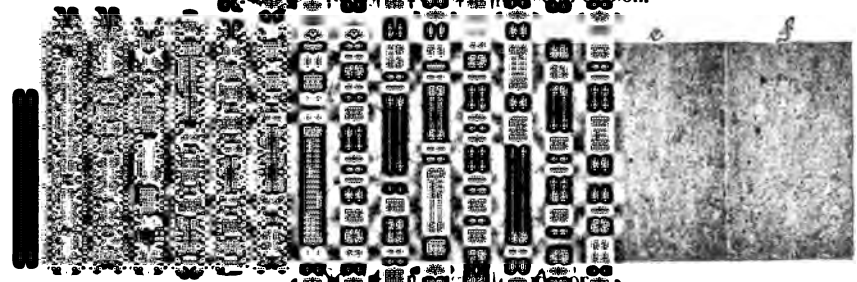

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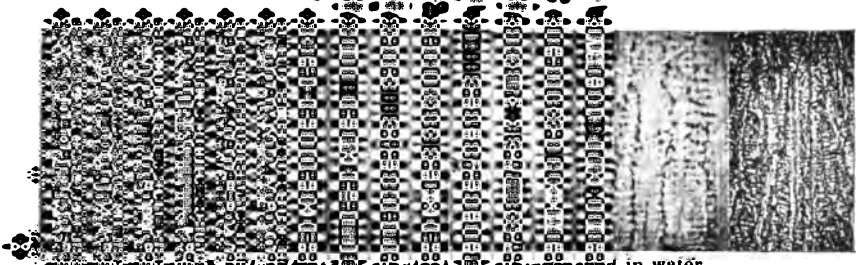

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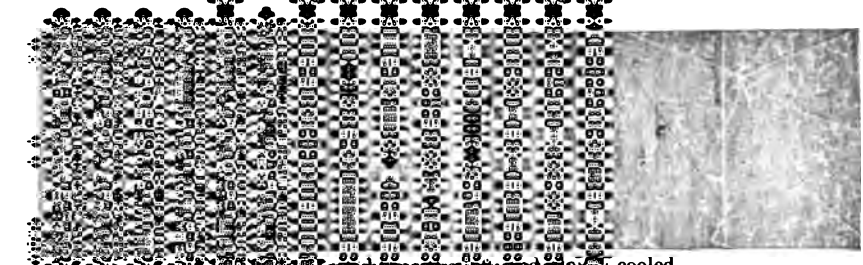

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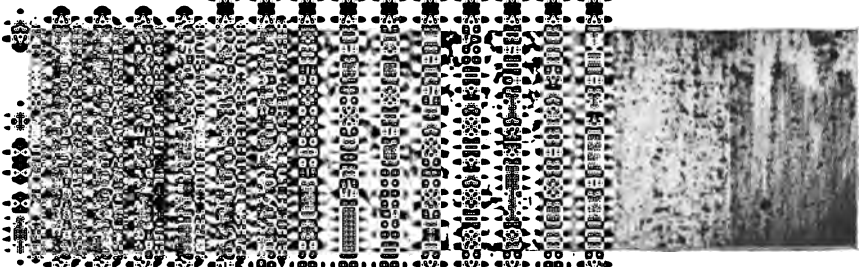

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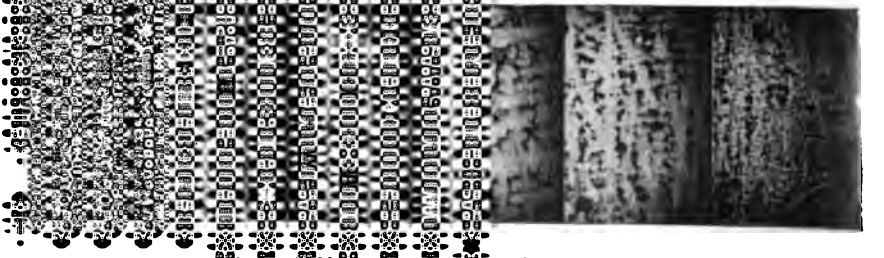

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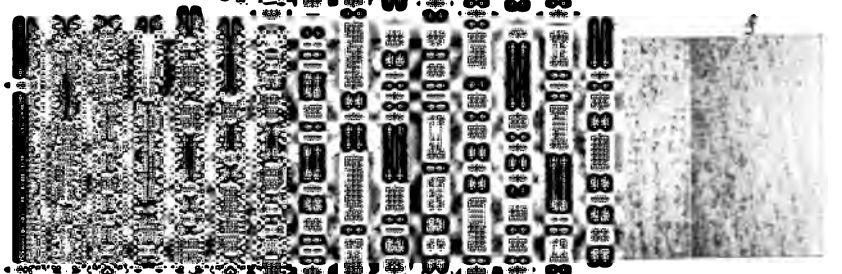

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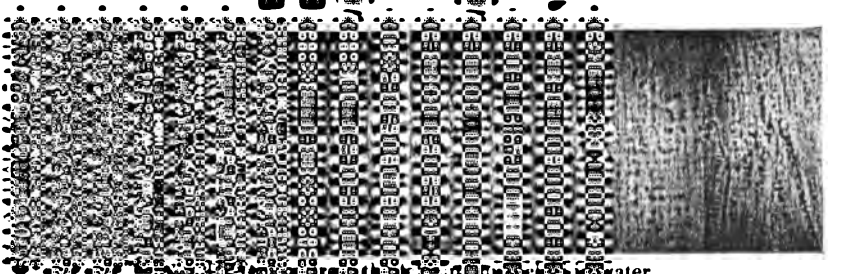

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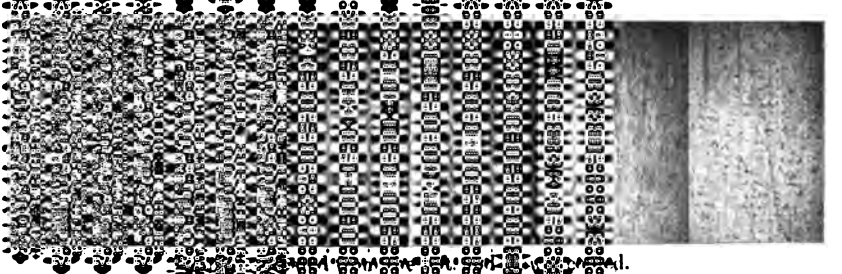

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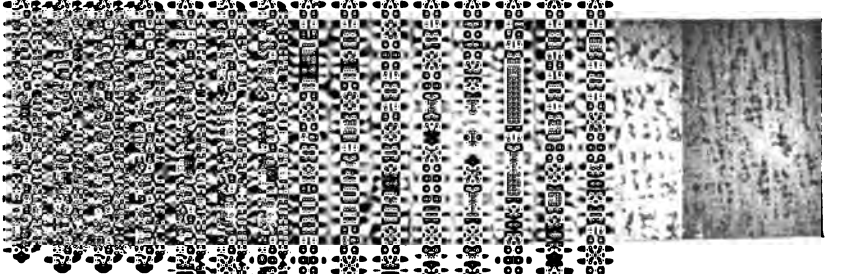

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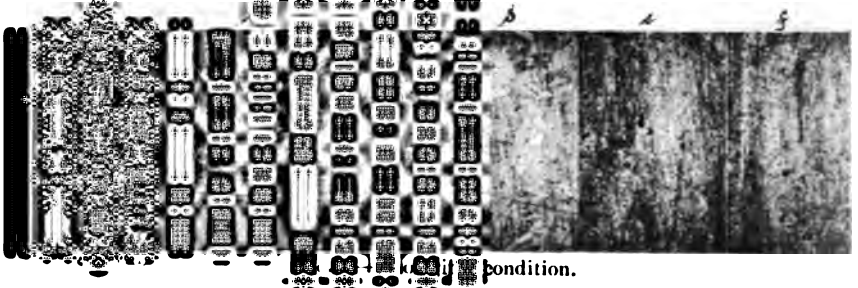

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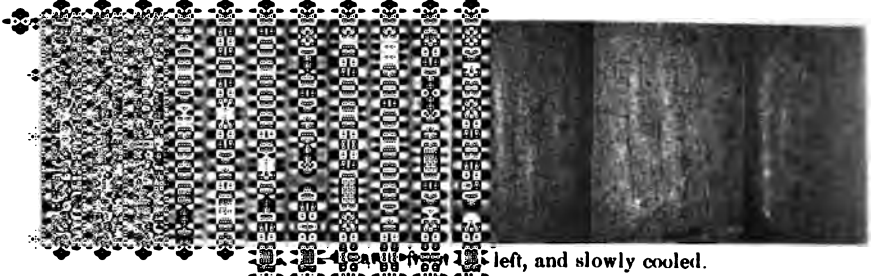

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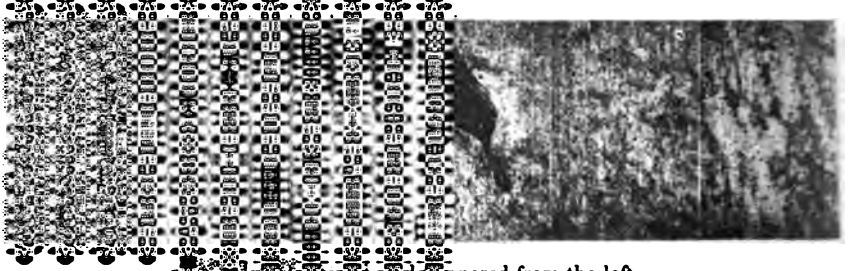

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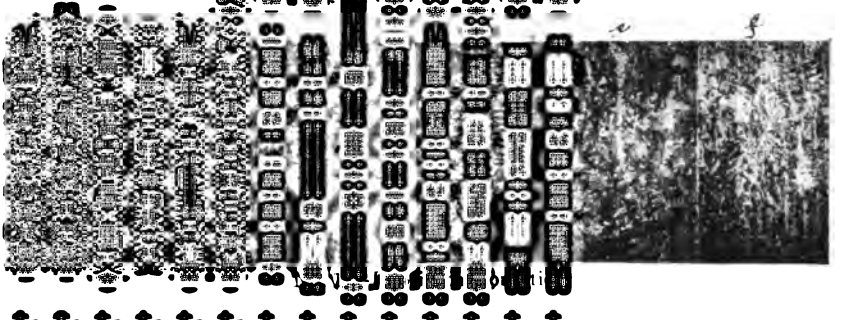

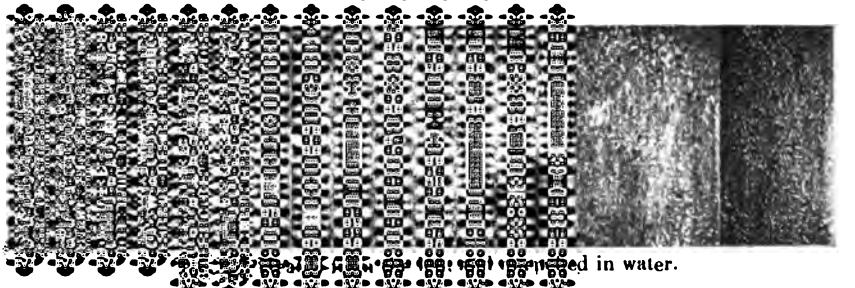

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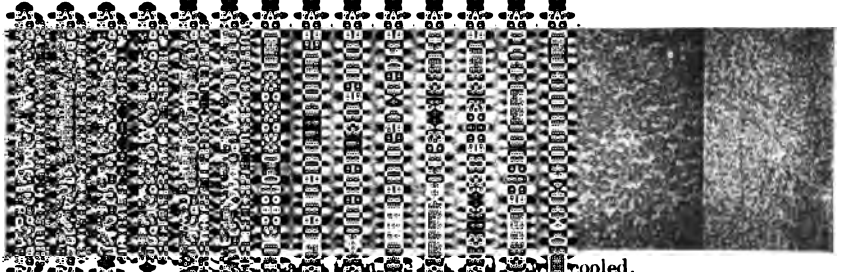

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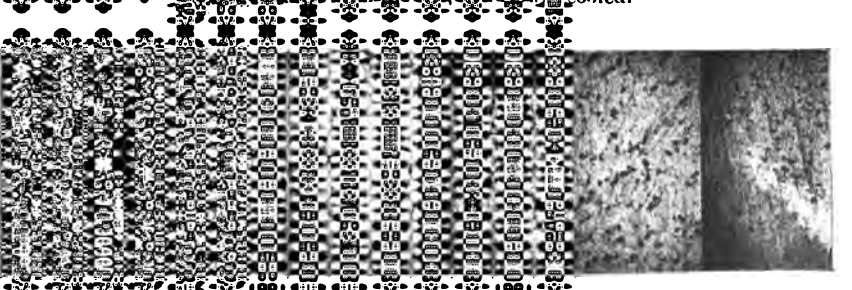

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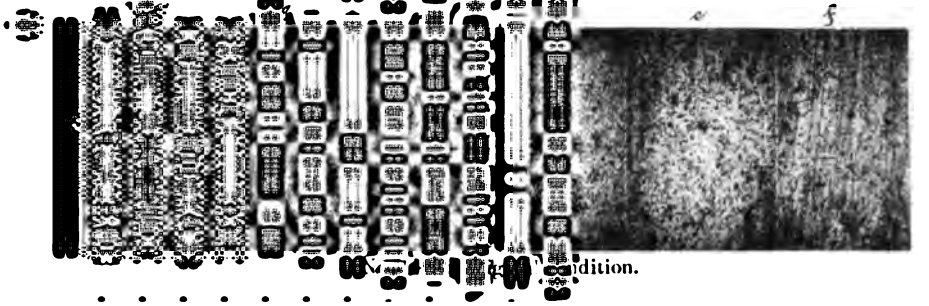

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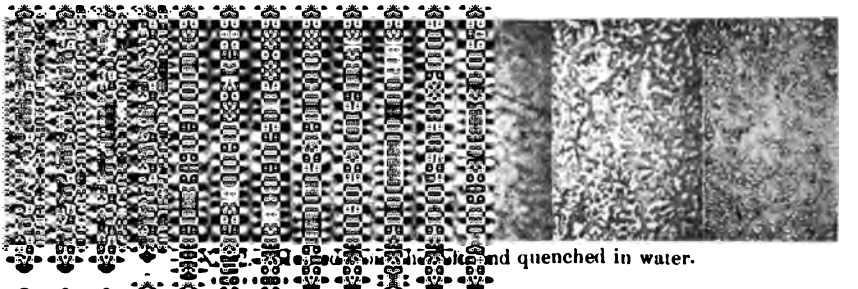

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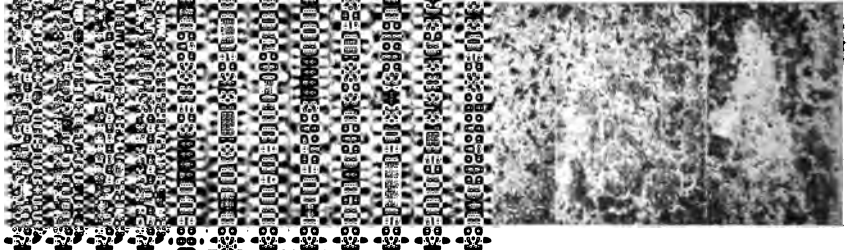

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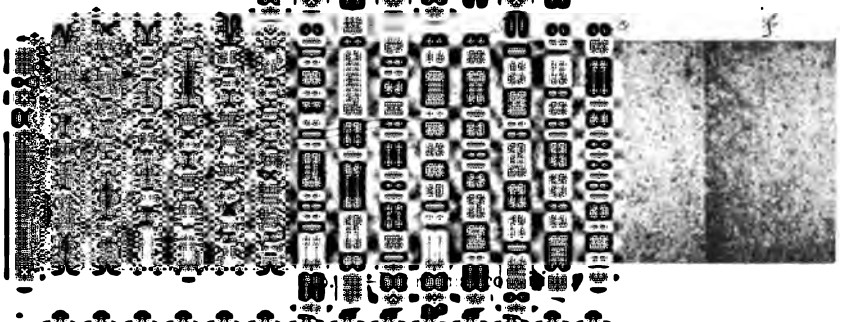

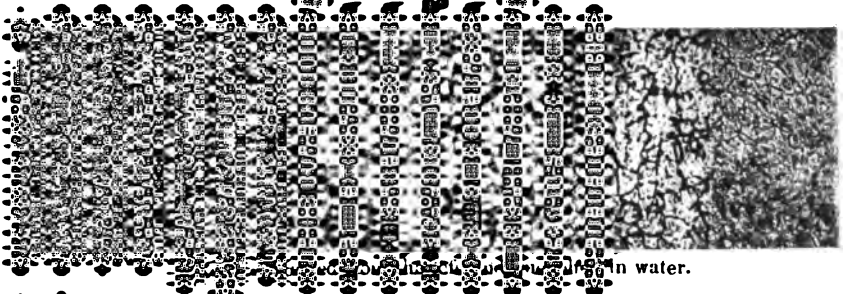

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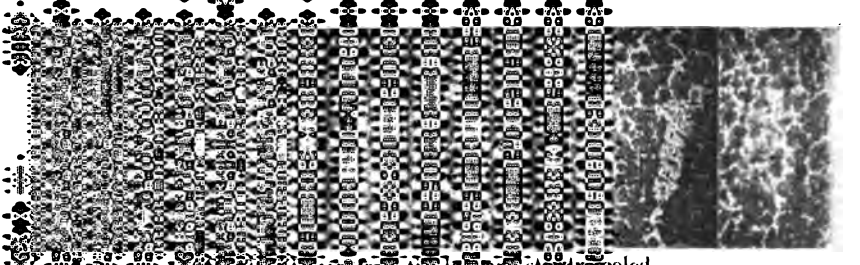

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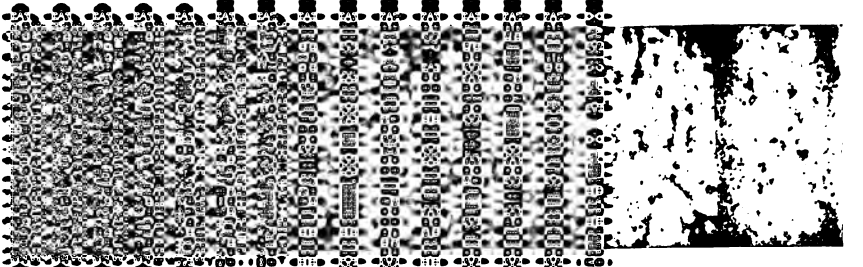

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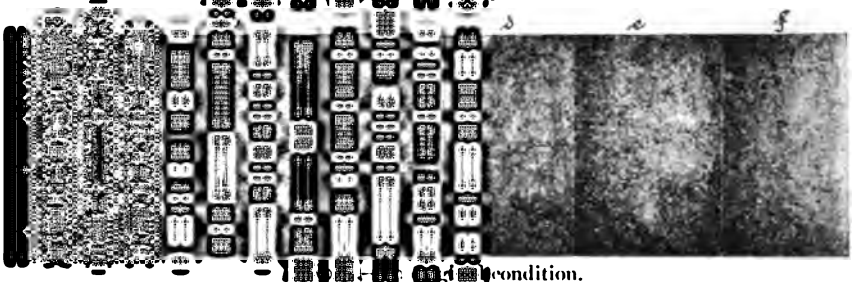

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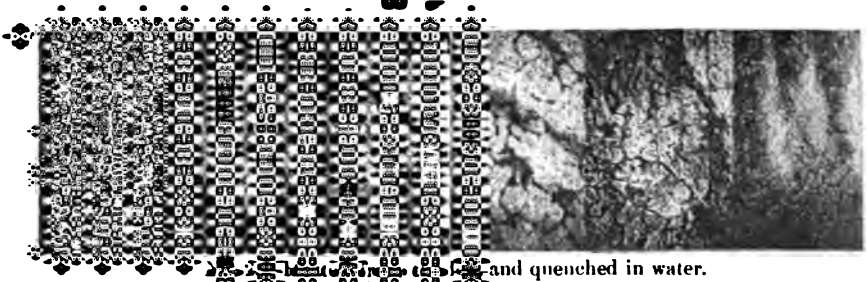

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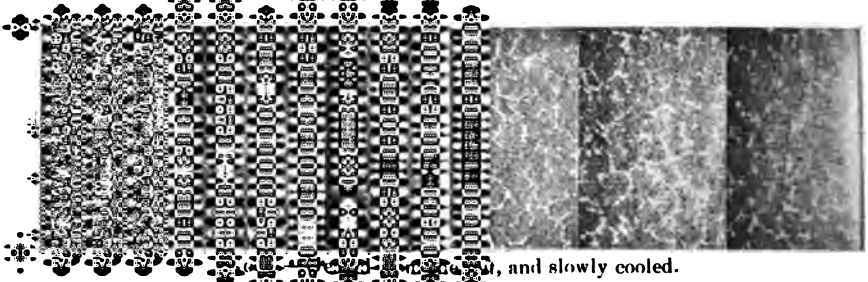

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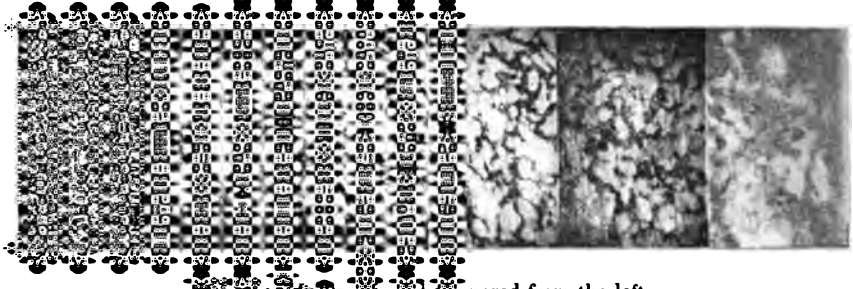

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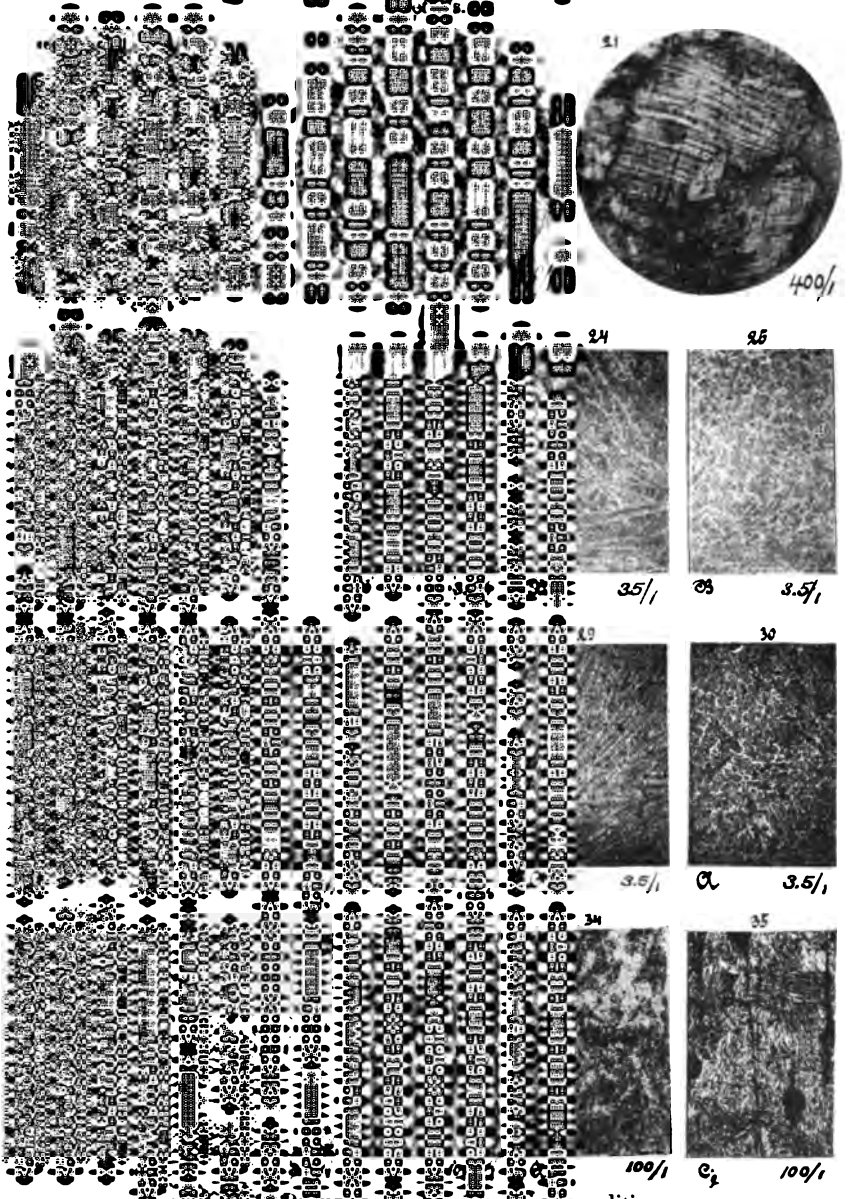

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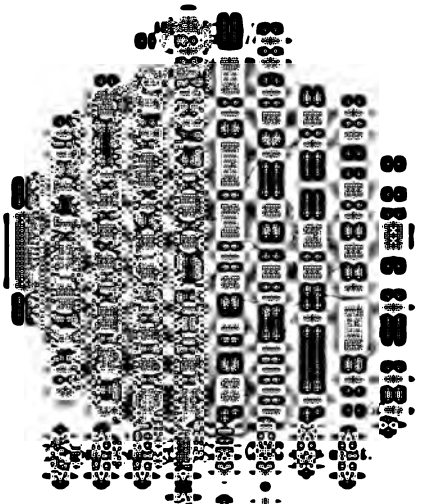


FIG. 2.

Open-hearth metal; C = 0.1 per cent.

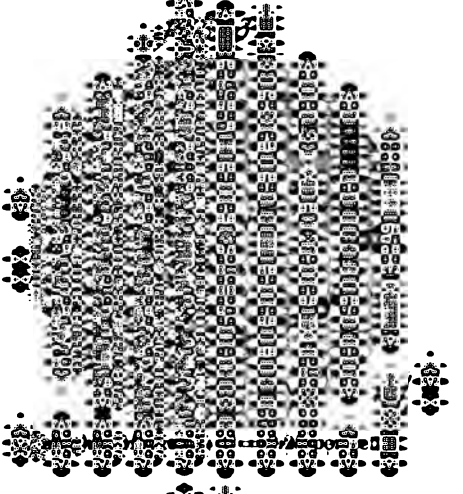
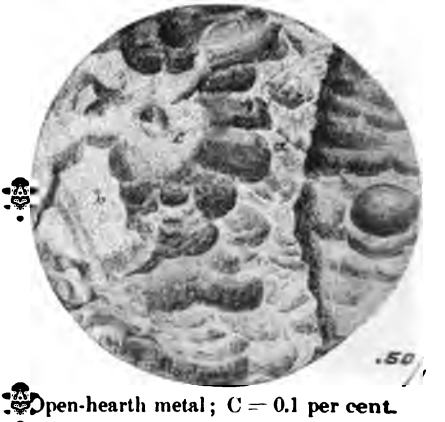


FIG. 4.



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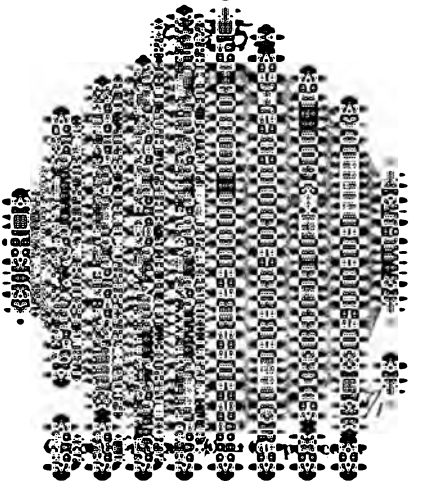
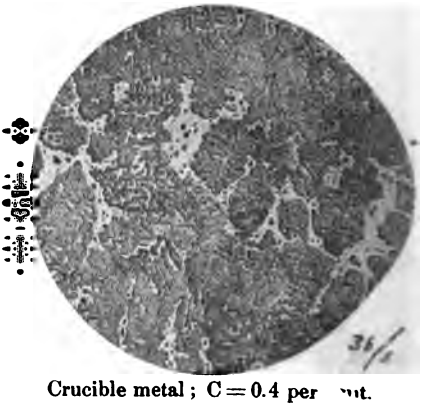


FIG. 6.



Crucible metal; C = 0.4 per cent.

circumscribed spots, the details of which appear in Plate I., Fig. 7, magnified 50 diameters. The high lights on the borders of the stems and on the dark mesh-spaces agree in character; they lie deeper than the low-lights, as may be seen in oblique illumination by the position of the light and dark edges (Plate I., Figs. 6, 7, and 10; Plate VI., $B_1 f$). The light falls upon the object from the right side. The fact that the bright surfaces lie deeper than the dark ones may be due to stronger etching at those places, or to the precipitation over the dark surfaces of a thick colored film.

Pores are often clustered in the border-lines of the grain (*i.e.*, of the rods). When they occur in the surface proper of the grain, namely, in the meshes of the net, they are embedded almost invariably in the bright spots, and only rarely in the blue surfaces. An impression is produced as if, in the forming of the grain, the pores had been crowded out of the mass into the bright borders. This arrangement appears on Plate I., Figs. 7, 12, and 13, and on Plate VI., B_1 *a* to *e*.

Toward the middle of the ingot (to the left on the plates) the elongated character of the grain passes into polygonal forms, and hence, in the polished sections, the contours of the grain show a reticulated veining of the high lights, and the dark-bluish surfaces form the meshes of the net. Here, to a far greater extent than in sections taken nearer the side of the ingot, the bright substance is covered with pores. They assume lengthened forms, and sometimes displace the bright mass entirely (Figs. $A_1 a$, $B_1 a$, and $C_1 a$). Where the latter occurs in broad areas, it is frequently covered with a brown-black film, which, in etching, gives the veins a darker color, but is more or less easily removed by gentle brushing (Plate VII., $C_1 a$ and *b*), or by rubbing the section with a soft cloth (Plate IX., Figs. 12 and 13, and Plate V., $A_1 c$).

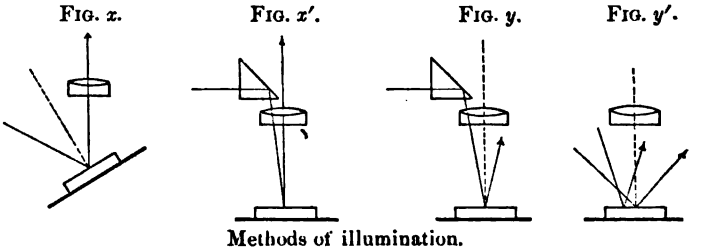
The pores may be distinguished in the polished section before it has been etched, but by the action of the acid they become more sharply defined and somewhat enlarged. After the grinding and polishing, and before the etching, therefore, the pores indicate more or less distinctly the general outlines of the grains.

Thomas Samples, No. 1.—In prepared sections of Thomas metal, especially of the softer grades, it is far more difficult to produce with etching sharply separated elements of the structures. On other occasions, I have endeavored in every conceivable way to develop appreciable differences between adjacent elements, but, thus far, without having found any reliable means, although I have become convinced

that eventually such means will be found. Since the fracture of Thomas metal shows a large coarse grain, and grain is developed in the surface of fracture only because of the existence of certain surfaces (corporeal contours) in the mass, which offer less physical resistance than the ultimate constituents of the grains themselves, I am convinced that there must be means for revealing, under the microscope, the limits of the grains on the sections. The structure thus disclosed could hardly have any other than a retiform character, with the several groupings which we have already considered.

But when we examine the structure of the Thomas metal D, Plate VIII., developed by etching with an aqueous solution of chlorhydric acid, we find it very different from that above described. The upper row of illustrations, D_1, conveys an idea of the difference. Examined by reflected light,* the same as used in taking the photographs, the surfaces exhibit the following features: At the side of the ingot (to the right on Plate VIII.), the predominating componet is a dirty, blue surface, marked with irregularly grouped and irregularly formed silver-gray areas, which occasionally produce the

* By *reflected* light I mean that kind of illumination in which the upper, illumined, opaque surface of the object casts the light into the tube of the instrument precisely, or almost, in the direction of the optical axis. For weak objectives, this may be accomplished as in Fig. *x*, and for strong ones as in Fig. *x'*.



Methods of illumination.

I speak of *vertical* light when the rays fall perpendicularly upon the illumined surface of the object and are reflected at the same angle (Fig. *x'*). *Oblique* light is that produced when the incident rays are so directed that the line of the reflected rays does not coincide with the optical axis of the instrument (Fig. *y*). Where all parts of the object do not lie in the same plane, oblique illumination creates shadows on the lower planes and bright edges on the higher ones, as we have already seen. *Diffused* light is the expression by which I describe the illumination when no pencil of particularly directed light-rays (such as those in Figs *x'* and *y*) is used, but when the light (day-light or lamp-light) strikes the object from all sides, and the surface of the object is set perpendicular to the optical axis (Fig. *y'*) Oblique illumination always may be assumed in the case of Figs. *x* and *y'*, as there the light is always derived from a window or a lamp.

impression of floating in the blue fields. Toward the middle of the ingot, these areas become more distinct and have a more definite contour (D_1 *d* to *a*); they cast shadows upon the dark surfaces and show fine borders of light on those of their edges facing the light. The bright areas, therefore, are in relief with respect to the dark ones. Between the larger surfaces, and occurring more numerously at the sides than in the middle of the ingot, are smaller, generally rounded, bright, and likewise elevated spots, sometimes assuming elongated forms which are apt to betray a parallel arrangement. The sides of the bright areas, also, are sometimes bordered with these spots (see drawing of a surface etched in aqueous chlorhydric acid, Plate XIV., Fig. 1). The blue fields are covered with pores especially toward the middle of the ingot; occasionally, also, pores are found in the bright areas, in which cases they are frequently in contact with the above-mentioned border-stripes. In diffused light the bright areas also appear silver-gray, and are, perhaps, even more sharply relieved against the dark surface.

The Thomas metal E (Plate IX.) is harder than D (Plate VIII.), and more nearly approaches Bessemer metal in its carbon-content. Upon treatment with chlorhydric acid in water, its characteristics furnish a transition to the phenomena of the Bessemer metal, with which we have become familiar. By reference to the test-strips, Plate III., it is apparent that in the case of samples D_1 and E_1 a margin was formed in etching, possibly as the result of the protection which may have been afforded by a film derived from the wax-cement. In this slightly etched area of the metal E, the development of rod-like, elongated grains on the sides of the ingot may be distinctly recognized, and from the bright contours of these grains parallel stripes or spines are seen extending into the dark gray matrix of the grain. The spines and the contours are brilliant white surfaces, exceeding in their aggregate area the dark surfaces in the field of view. Towards the middle of the ingot the structure of the slightly etched border-zone disappears almost wholly; it is seen only faintly shimmering through, while just to one side its appearance is sharp and clear. As an illustration of how easy it is to be deceived if the work is not conducted with the greatest care, I have pictured on Plate IX., E_1 *d*, the border of a blow-hole, which shows on the right a faint marginal zone produced in this way by the side of an area of sharply defined structure. Upon more strongly etched surfaces, such as those of Figs. E_1 *a* to *f*, the structure also appears, and it is just possible to recognize the bacillary development of the

grain (Fig. $E_1 f$). Irregular and promiscuously grouped bright surfaces appear (Fig. $E_1 f$), similar to those of D_1, and like them they frequently contain pores. Near the middle of the ingot the contours of the grains appear as fine veins, set in relief on a dark surface (Figs. $E_1 b$ and c), and containing pores like the Bessemer metal. These pores are always very small, and of rounded, bean- and pear-shaped outlines, passing into elongated forms under the conditions previously described. In the middle of the ingot, however, they are grouped like nests, finally merging into cavities bordered by the tattered, reniform ends of dendritic crystals (Fig. $E_1 a$), such as are often observed in very perfect forms in the blow-holes and cavities of surfaces of fracture and polished sections.

Open-Hearth Samples, No. 1.—The sections of open-hearth metal resemble those of Bessemer metal in exhibiting the same shades and sharply defined areas of blue and yellow. The relation of the aggregate area of light to dark surfaces decreases with a rising carbon-content. In strip F_1 (Plate X.), the proportion of the light area to the whole field of view may be estimated at about eight- to nine-tenths. The blue patches are separate and irregularly scattered, showing a dirty hue, often toned into gray. The light-colored matrix varies in shade from a dirty yellow to yellow-brown. Many pores are conspicuous toward the middle of the ingot; a little nearer the middle they become bunched in knots with radiating veins, and gradually form a coarse net-work (Figs. $F_1 c$ and d), in which a dark-blue central furrow lies well defined between two bright-yellow borders. The limits of both these borders, in turn, are fairly well defined against pale-blue patches bedded in a yellowish matrix which fills the meshes of the net (Plate XIV., Fig. 2, etched in aqueous chlorhydric acid.) The dark-blue furrows lie deepest in the object. The yellow surfaces are covered with many fine pores. In the pale-blue patches scarcely any pores occur, though they are sparingly found in the blue veining.

The test-strip G_1 (Plate XI.) shows well-defined, silver-white patches in a blue field. At the side of the ingot (to the right on the plate) they exhibit a regular grouping in sets of parallel lines that cross one another frequently at interfacial angles of 60° or 90°. The white patches predominate; they occupy about six-tenths of the visible field. Numerous fine pores are discernible, particularly in the bright mass. Toward the middle of the strip this mass assumes a yellowish shade, with brownish spots; further on, broad yellowish veins appear as a net-work, the meshes of which are closely

strewn with bright-yellow spots. Approaching the other end of the strip (*i.e.*, the middle of the ingot), the breadth of the bright veins continually increases and the spots in the meshes become less numerous. Still nearer the end, the principal veins become more and more covered with a brown, granular, well-defined stripe (central furrow), or with rows of pores which finally pass into completely developed cavities. In the transition-stage, a third sharply segregated mass is frequently conspicuous in the middle of the bright veins; it represents the contours of the grain, and in most cases includes the pores (Plate I., Figs. 11, 12, 14; Plate XI., Figs. G_1 *a* to *f*; and Plate XIV., Fig. 3, etched in aqueous chlorhydric acid). Everywhere the light surfaces lie higher than the blue.

The sample of open-hearth metal H (Plate XII., top row) bears a general structural resemblance to the sample G, except that there is a still greater excess in the aggregate area of the sharply-defined, bright, yellowish surfaces over that of the blue. It may be estimated at seven- to eight-tenths of the entire field of view. The yellow surfaces are in relief. At the side of the ingot (to the right on the plate) the veining is more confused; the meshes of the network are still more covered with small bright spots, the net itself is more prominent, and elongated surfaces of the grain are less distinct. In other respects the description of the open-hearth metal G applies to the metal H.

Partial Summary.—If we summarize and compare our descriptions of the structure of cast ingot-metal in its original, unwrought condition, we notice as the first contrast between Bessemer metal and Thomas and open-hearth metals, that the bright veins lie deeper in the first and higher in the last two than the blue and dark-gray fields. For the purpose of acquiring more positive knowledge on this point, I measured the difference in elevation directly, with a magnifying power of 180 diameters, by bringing contiguous parts successively into exact focus. Measurements carried out in this way at different points of the object showed that the difference in elevation between the bright veins and the adjoining dark surfaces of the matrix was as follows:

Bright veins in samples.	A.	C.	D.	F.	G.	H.
Average height above matrix, in mm., .	.....	.....	0.0002	.....	.....	0.0023
Average depth below matrix, in mm., .	0.0051	0.0006	.....	0.0006	0.0012	.....

These measurements supply reliable data for A and H only, since

in all the other cases the results fall within the limit of error of the method. I attach greater importance, however, to the previously described light-and-shadow indications of relative elevation, though I am free to admit that the same phenomena might occur if, as in Figs. *z* and *z'*, there should be a depressed rim between the two sur-

FIG. *z*.

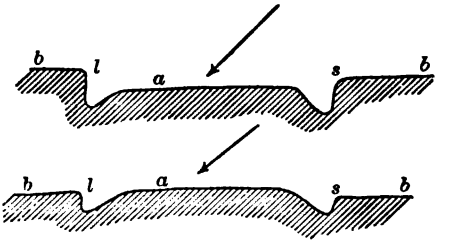


FIG. *z'*.
Hypothetical conditions of the etched surface.

faces,—a condition which is not at all probable and has never yet been identified. When the dark surface *a* lies lower, as well as when it lies higher than the light surface *b*, a bright edge must be formed at *l* and a shadow at *s*. In making other examinations, I have found very distinctly after etching that the veins lay deeper than the mesh-surfaces of the net. Selecting a special small test-piece from Plate F, I divided it in halves and strongly etched one part (*a*) in its original state with a solution of nitric acid in ether-alcohol (about 1 to 50 + 50). The resulting etching was extraordinarily well defined, the strongly attacked surface of the section being bright as a mirror and showing extremely delicate details, which were beautifully developed. The measurement of the elevations showed that points *b* and *c*, Plate XIV., Fig. 4, lay respectively 0.0122 and 0.0221 millimeters lower than point *a*. The ridge *a* corresponds with a light-colored vein, and *b* and *c* with dark-meshed fields of the open-hearth metal F. The second part (*b*) of the small test-piece was heated white-hot, and then quickly cooled and etched like (*a*). Its structure is shown in Plate XIII., Fig. 20, magnified 100 diameters. The white spots are raised, the dark ones are depressed.

Under high magnifying powers (apochromatic objective with 0.30 aperture and compensating eye-piece 12 of Karl Zeiss, Jena, enlarging about 360 diameters) the blue and dark gray surfaces of all the foregoing sections show, generally speaking, a granular structure. In weak etchings, such as I commonly employ, and such as have been used exclusively in the preparation of the sections illus-

trated on Plates V. to XII., the grain does not always appear with uniformity and regularity. Usually it is most distinct at the edges of the dark surfaces. Sometimes it is possible to detect a species of stratification due to a certain interflow of the grains, while occasionally there are feathery groupings, like those on crystals of spiegeleisen.*

If the corroding action is carried very far, as in test-piece (*a*) of the metal F, Plate XIV., Fig. 4, the component of the bright vein-surfaces (point *a* in Fig. 4), most resistant in the ether-alcohol solution of nitric acid, exhibits a cross-section in which these feather-and-branch forms and, occasionally, granular figures, are remarkably well defined, showing that even this constituent of the structure is attacked, though with difficulty, by the highly diluted nitric acid solution. A granular character of the white surfaces is also indicated in Plate I., Fig. 7. As a rule, it is difficult to reproduce these details by photography in such a way that the picture shall satisfactorily represent the constitution of the surfaces. The areas to be dealt with emit very narrow pencils of rays; light and shade vary, therefore, with the displacement of the tube, the conditions seeming to favor the formation of interference-lines, and only by very exact focusing is it possible to obtain at a few points of the picture figures of such clearness that the eye, but not the photographic plate, can adjust itself to seize the details. That the difficulty here referred to may be better appreciated, I have prepared Figs. 15 to 18 on Plate VII., and Fig. 19 on Plate XIII. with special precaution. Manifestly these pictures scarcely could give a stranger an idea of the true relations; indeed, they disclose very few of the details which we have discussed or may yet discuss, though they have been taken with the greatest care and with the aid of every favorable device and artifice. The drawing, Plate XIV., Fig. 4, on the other hand, would probably convey a fairly correct impression to every one, especially when examined at a distance.

The granular nature of the substance of the dark mesh-surfaces may be inferred from the appearance of the deeply etched parts, such as those drawn at *b* and *c*, Plate XIV., Fig. 4, and from the features of Fig. 18 on Plate III. But whether this granular structure is peculiar, as I assume, to these dark meshes, can be determined only from the appearance of the surfaces (for example of *b*

* For an illustrated description the reader is referred to my paper "Zur Mikrostructur des Spiegeleisens," previously cited.

and *c*) when it has been positively established that they are remnants of the more easily attacked component. Frequently the slopes between the higher and the lower planes are likewise covered with grains, although as a rule elongated, parallel swells and feathery forms predominate, like the figures described as characteristic of the cross-sections of the chemically more resistant substance. It is reasonably certain that the upper parts of these slopes represent the exposed surfaces of the resistant substance, and hence, in seeking a cause for the granular character of these surfaces one may well hesitate whether to assume a granular structure as peculiar to one or the other of the constituents that are separable in dilute acids, or as common to both. If one constituent solidifies before the other, the more fusible one will presumably envelop the one already solidified, unless, indeed, the latter should remain soft, in which case the grains of the constituent which solidifies last being possibly the harder, might imprint themselves in the still plastic mass of the other constituent. At all events it is apparent that no safe conclusions upon the structure of either substance can yet be drawn from the phenomena of strongly etched sections. A certain structural arrangement of one or the other may be regarded as demonstrated only when a given treatment invariably and unquestionably produces absolutely constant phenomena on the weakly etched surfaces of like materials, under like conditions.

If the phenomena of the etched surfaces and sample-strips be investigated with higher magnifying powers, some of the spots which we have been designating as pores resolve themselves into dark gray, smooth, more or less circular areas, which appear like embedded bodies. Two such surfaces are shown in connection with a real pore at *a* on the right side of Fig. 14, Plate I. I have not yet been able to determine whether they represent slag or something else; they certainly differ from the otherwise almost invariably round form of included slag in cast ingot-metal (Plate VIII., D_3 *a* and D_4 *a*). In rolled ingot-metal the pressure of the rolls lengthens the form of the cross-section of the slag-inclusions.

The bright substance in the light-colored veins (Plate XIV., Fig. 3), which has repeatedly attracted our attention by its sharp separation from the surrounding mass, may probably be another special component of the structure, but as yet I have not succeeded in establishing its character by incontrovertible proof. A circumstance of possible bearing on the case is that the parallel spines which start from the borders of the grains, presenting a regular arrange-

ment, notably at the leafy edges, and penetrating into the body of the grain or mesh-surfaces, are frequently less well-defined against the meshed field than are the border-zones. On Plate XIV., Figs. 5 and 6 represent crucible-steel of medium hardness from Bochum with 0.4 per cent. carbon, etched in aqueous chlorhydric acid. In Fig. 5 a magnifying power of 25 diameters shows that the borders of the grains consist of well-defined, non-continuous white surfaces, from which, yet not coming into actual contact with them, the parallel spines extend.

The origin and cause of the blue and brown furrows in the veins of the network, which have been repeatedly referred to and illustrated, cannot at the present time be ascribed to a special structure-builder; the subject is one for further study.

The degree to which the etching is carried always exerts a noticeable influence on the structural phenomena, though rarely injuring their characteristic qualities. But that such injury may occur, my experience on a former occasion has shown.* Aside from this, however, the kind of reagent employed exerts an unmistakable effect on the appearance of the structure. This may be readily seen by comparing Figs. 23, 24, 25, 28, 29 and 30 on Plate XIII. with the series A_1 and B_1 on Plates V. and VI., taken from the same cross-sections of the ingot. The two series were etched in aqueous chlorhydric acid, while the plates which furnished the figures on Plate XIII. were treated with nitric acid dissolved in ether containing a little water. This latter mode of etching has produced sections characterized by a dark, uncolored ground from which the bright surfaces stand out sharply; it is true, the light substance is also attacked by the acid, for the fine white lines in the surfaces of the

* When the etching was started a very different picture appeared to that which afterwards remained; and apparently the result was not affected by the use of either water or alcohol with the chlorhydric acid. On the surface of the head appeared a confused picture of promiscuous, arborescent skeleton-crystals such as may be found on an etched section of cast, unwrought steel. The contours of the figures were not well defined; the figures lay, so to speak, like a heap on the surface (compare Plates V., VI. and VII., bottom rows). In the web-surface and in the passage from the web to the head, a somewhat more distinct banding appeared, parallel with the axis of symmetry of the profile. . . . . One almost becomes convinced that the structure which appeared first is due to the displacement of the mesh-particles by the mechanical action of the rolling, and that the network which appeared later (light on a dark ground; compare Plate XIII., Figs. 31 to 38) represents the effect of chemical reactions during the cooling of the rail, after rolling." (Translation from *Stahl und Eisen*, 1892, p. 414, "Das Gefüge der Schienenköpfe.")

grains in $A_1 f$, and $B_1 f$, are wanting, and instead of the blue, fine-grained portion, the plates show a much coarser grain, just distinguishable by the depressed veins in Figs. 25 and 30, but more conspicuous in Fig. 26. As a further result of etching with nitric acid, the white parts become far more distinctly isolated, appearing as disconnected rows of dots (Fig. 27). The use of an alcoholic solution of chlorhydric acid produces likewise an extraordinarily sharp separation of two structure-builders, and thus is particularly suited for photographic reproduction because the less actively corroded parts appear in brilliant white on a dark ground (Plate XIII., Figs. 31 and 33; structure of a Bessemer rail).

Frequently the different elements of the structure can be brought out by simple polishing, especially when it is done on a soft support, like rubber (Plate XIII., Fig. 32); the harder parts then remain in relief.

The experiences above recorded may serve to show that very much attention will still have to be devoted to etching-methods. By depending on a single, perhaps imperfectly applied, method, one may easily be led to wrong conclusions, as I pointed out in the work already referred to on *Das Gefüge der Schienenköpfe.*

In the foregoing descriptions of structural components I have purposely abstained from assigning special names, or dwelling upon the discoveries and reports of others, not with the intention of depreciating from their merit, but because I wish to be free to present that only which can be directly deduced from the objects here examined. The many accepted modes of designation, the speculations on the building up of the structure, on the function of this or that kind of carbon in it, and on the ultimate nature of the structure itself, can obtain a firm basis, as I pointed out in the introduction, only when microscopic metallography shall have become a really practicable and reliable tool, with which it shall be possible to characterize accurately and positively the several components, and on all occasions recognize and determine them without doubt or question. But to accomplish this, years of discerning labor with a steadfast aim are required. How wide of the mark our investigations of the microstructure of iron still are, every thoughtful reader will infer from the numerous disputes in which different investigators become involved. The actual, half-evolved status, confused by theories that have been factitiously read into the subject rather than developed out of it, has given currency to wrong views; and these, when

embodied in metallurgical text-books, will, unfortunately, be productive of far more harm than good.

Hardened Samples, No. 2.—Let us now examine very briefly the modified structures that have resulted from heating and various modes of cooling, as illustrated in the lower three rows of photographs on Plates IV. to XII.

In the strips No. 2, which were heated at one end and plunged into water, the Bessemer metal shows under strong magnifying power (apochromatic objective, with 0.30 aperture and eye-piece 12) an extremely well-defined, close grain on all its superficial areas —on the dark as well as on the few light and not sharply bounded areas that occur at the unheated end of the test-piece (Fig. $A_2 f$). At the unheated ends, the components of the grain exhibit a most disordered grouping, there being scarcely any difference in this respect between the light and dark elements. Toward the middle of the strip the light portion becomes blurred, and all semblance of a regular arrangement of the spots (the contours of which were at first fairly distinguishable, as in Figs. $A_2 f$, and $B_2 f$) is gradually obliterated. Near the middle the contours are still further effaced, and in the perfectly uniform grain only dark shadows are observed, enclosing a lighter, dendritic skeleton. In the border-lines of the grain near the side of the ingot an occasional bright stripe occurs, differing from the rest of the light-colored substance by its luster and by having rows of round pores. Toward the middle of the strip these shining masses group themselves in the spaces between the branches of the arborescent crystal, frequently as centers of dark shadows (Fig. $A_2 f$, right side). Pores occur in these spaces also, and an impression is created as though the bright parts and the pores had been segregated out of the mass and crowded into the borders of the grains. As the heated end of the strip is approached, the granular structure of the mass assumes a more regular character, but, in the case of the test-pieces of the metals A and B, one difficult to describe or even to draw. The grains become lengthened and occasionally have the feathery form once before described; even separated surfaces with definite contours can be recognized, and they certainly can owe their appearance only to the orderly arrangement of the grains (Plate XIII., Fig. 34). In the case of the test-piece of metal C, on the other hand, which contains higher carbon, and may have been heated more than those of A and B, the surfaces are more sharply bounded, and the grains in them are grouped in sets of parallel spines differing in direction in adjoining areas (Plate

XIII., Fig. 35). I have not been able, however, to discover a distinct stratification in alternately soft and hard plates as in the manganese steel represented on Plate XIII., Fig. 21, magnified 400 diameters. The gradual disappearance and resolution of the bright surfaces toward the middle of the test-strip render it difficult for me to believe in a constant composition of the iron carbide, for that is what the light-colored substance is usually said to be.

The samples of Thomas metal D_2 and E_2 (Plates VIII. and IX.) exhibit in their entire area a uniform, irregular grain, without any tendency to a striped or banded arrangement. On the whole, the grain is somewhat finer than that of the Bessemer metal A_2, B_2 and C_2. At the side of the ingot (to the right on the plates) smooth, bright, sharply-defined spots stand out from the dark, grained surface (Figs. D_2 *f*, and E_2 *f*). The sharpness of the outlines diminishes toward the middle of the strip and the spots grow duller; the grain increases in prominence, and soon the bright surfaces fade almost completely into the dark ones. Upon these, finally, at the heated (left) end only, a faint, dark veining, without sharp outline, is observable (Fig. E_2 *b*). The bright spots in Fig. E_2 *c*, may be due to weaker (defective) etching, since under the microscope no noteworthy differences of structure are discoverable in them.

The samples of open-hearth metal F_2, G_2 and H_2 (Plates X., XI. and XII.) show throughout a uniform grain, passing nowhere into a regular or stratified grouping. There is a difference between the first strip and the other two. In Fig. F_2 *f*, corresponding to the side of the ingot, the bright spots are remarkably well defined, and, as before, they gradually lose their sharp outlines, and begin to have a grain and enclose dark, ragged veins, which become more blurred toward the heated end of the test-piece. In metals G_2 and H_2 the structure is not so well defined at the side of the ingot, apparently owing to the insufficient etching; then follows a zone, in which the bright surfaces stand out fairly well. The dark, grained areas form the veining and the borders of the grains (I distinguish between the macroscopic grain of a surface of fracture and the microscopic granulation of both the dark and light substances). The bright areas lie like islands in the dark surface. The contrasts between the light and dark areas are more pronounced in the photographs than under the microscope. In metals G_2 and H_2 the white surfaces are at first rather minutely divided, and remain covered in many cases by dark patches, but toward the middle of the strip they gain in breadth. These bright areas betray signs of insufficient etching;

if the action of the acid had been stronger, it is to be supposed that they would have exhibited perfectly the granular character of the dark surfaces. A remarkable phenomenon may be seen in Figs. H_2 *b* and *e* (Plate XII.), where a few, fine granules of the light substance appear as brilliant white specks in the dark grain. These minute surfaces are distributed with fair regularity, like a network, in the mass, though the individual specks are rather far apart. Their shape is rarely round, but generally long, angular, spiked and branching.

Annealed Sample, No. 3.—The third series of test-strips, those heated at one end and slowly cooled, show very good and well-developed coloring for the Bessemer metal (A_3, B_3 and C_3, Plates V., VI. and VII.). In the dark granular mass there is a coarsely-meshed veining of a shining yellow substance, which is likewise, though somewhat more closely, granular at the side of the ingot, and shows distinctly in the unheated end of the strip the original borders of the grain. The dark substance is composed of variously colored granules, shading through all tarnishes from dark blue to dark straw-yellow. In this substance a fine retiform grouping of the like-colored granules seems to be of frequent occurrence, and becomes quite distinct as the heated end is approached. The veining of the principal meshes contains, therefore, a network of still finer mesh. In Figs. A_3 *b* and *c* this feature is well brought out, but in the illustrations of B_3 and C_3 the details are lost.

The Thomas metal D_3 (Plate VIII.) shows throughout a light gray, shining, granular substance, into which rounded spots of a darker gray have apparently eaten, and these spots occasionally reveal an almost black speck in the center. Further details are wanting. The Thomas metal E_3 (Plate IX.) shows also granular spots of deep-gray color, embedded in a light-gray, shining, granular mass. At the side of the ingot the form of the granules may be clearly recognized. Toward the middle of the strip, the dark masses distribute themselves increasingly over the light ones: while at first the lighter parts occupied about six-tenths of the field, now their aggregate area is reduced to barely four-tenths. Still further on, dark, blackish pores appear, mainly in the light substance, Figs. E_3 *a*, *c*, *d* and *e*. Arborescent skeleton-crystals occur on the edge of a blow-hole (Fig. E_3 *b*), but nowhere in the grain are striped areas to be seen.

In the open-hearth samples (Plates X., XI. and XII.) a dark, dirty-yellow granular substance contains a bright and likewise

granular veinwork, which takes up most of the pores, and, in places where it is more broadly developed, shows the segregation of a white, connected, sharply-defined, central vein-thread (Fig. G_3 *e*). The outlines of the net-work at first (on the right-hand of the series) are sharp; toward the middle of the strip, and beyond it, they lose a little in this respect, yet may be readily distinguished everywhere. Near the heated end of the strip the dark meshes are marked with still darker veins composed of either continuous lines or rows of multiform granules. In all the open-hearth strips, F_3, G_3 and H_3, instead of rounded forms, the granules have irregular, feathery shapes.

Tempered Samples, No. 4.—The test-strips No. 4 of all three Bessemer samples (Plates V., VI. and VII.) appear to have been only weakly etched, since the granular structure of the light surfaces is but faintly revealed. During the etching extraordinarily well-defined dendritic figures appeared (see the photographs of the strips, Plate II.), and for that reason, unfortunately, the action of acid was interrupted too soon. Under the microscope the sharpness of the definition is considerably reduced. The dendritic surface-forms, as may be observed, are composed of light-colored skeletons, and the interstices contain pores surrounded with a dark penumbra. Only in part do the pores produce the impression of having been present originally as hollow spaces. Most of them show corroded sides, in which the acid has always distinctively revealed the granular structure, the latter consisting usually of irregular groupings of feathery forms, or more rarely of rounded bunches.* The dark surfaces have generally, though not always, the same structure. The illustrations in the fourth row of A, B and C depict the general character very well, although the contrasts have been, perhaps, too strongly accentuated by the photographic reproduction.

Quite a different general character is developed for the fourth set of strips of the Thomas metal D and E, as, indeed, the illustrations plainly indicate. In them a uniform, dark, granular mass is covered only with innumerable round pores, irregularly scattered over the surface and producing an impression as if the acid had been applied at random to any spot and had corroded the material around it. One is not convinced that the depressions here coincide with the structural upbuilding of the material, but rather that their disposition is purely arbitrary. In only a few places the pores are

* The figures developed on strips Nos. 2 and 3 present in many respects similar phenomena.

gathered in a sort of fascicled arrangement, but dendritic groups do not occur. The pores create the same impression in open-hearth as in Thomas metal, except that they are clustered like nests in the knots of the network and tend to follow the lines of the netting rather than spread over the surfaces of the mesh. In open-hearth metal F_4 (Plate X.), especially toward the tempered end, the meshes are overdrawn with a fine dark veiling, which defines fairly well the limits of numerous bright spots. The substance of the latter as well as of the dark mass and the ground of the pores show a distinct granulation.

As the day set for the delivery of this paper has already been passed by several weeks, I am obliged to terminate it now. Unfortunately, there are several doubtful points which I have not been able to clear up; and I regret this all the more, as pressing duties in other directions will prevent any further prosecution of my microscopic work for a number of months. After the erection of a special laboratory for these investigations at the Mechanico-Technical Experimental Station, however, I hope to repair the present deficiencies, and I hope, also, that the expressions of professional opinion from those to whom this paper is submitted may encourage me in my efforts and spur me on to further research.

EXPERIMENTAL INVESTIGATIONS ON THE "LOSS OF HEAD" OF AIR-CURRENTS IN UNDERGROUND WORKINGS.

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(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

I. ANALYTICAL EXPLANATION OF "LOSS OF HEAD."

THE circulation of air in underground workings is subject to a gradual and continuous reduction of its pressure, from intake to outlet, caused by the friction between it and the more or less rough and uneven surfaces of the passages. For comparison with the flow

* Translated by E. G. Spilsbury, Trenton, N. J.

of gas and water, we shall maintain the classical term of loss of head (*perte de charge*) to designate this diminution of pressure in the underground air-currents, and, according to custom, we shall assume it to be measured by the column of water which it maintains in equilibrium. Throughout these investigations this height will be designated by the letter h, and will be expressed in millimeters because the millimeter of water has the advantage of corresponding to the pressure of 1 kilogramme per square meter; that is to say, the unit of weight per unit of surface.*

The conception which we must hold of the friction of air against the sides of a gangway is very different from that with which the study of the solid members of machinery has rendered us familiar. In this case we no longer have to deal with surfaces more or less lubricated and greasy, sliding on one another, but rather with an incessant restoration of speed and of direction given to the innumerable minute streams of air which are broken up and diverted against the irregularities of the enclosing surfaces. Under these conditions, it is easily demonstrated that the pressure lost in maintaining the desired conditions, or, in other words, the loss of head, increases in a direct ratio to the density of the air and to the square of the average speed of the current. On the other hand, it also appears evident that this same loss of head must be proportionate to the extent of the frictional surface of impact. If, therefore, we introduce a given numerical coefficient which will take into account the possible differences between one gangway and another, due to inequality of the contact-surfaces and the changes of direction, we shall find ourselves in possession of all the necessary elements to express this dimension geometrically.

Its analytical form is easily obtained in expressing by an equation the equilibrium to be maintained by the opposing forces. For example, let the distance A to B (Fig. 1) represent a portion of a horizontal gangway having a length L, in which the air-current flows in the direction of the arrow, and in which the profile is regular enough to assume the hypothesis of an average uniform section, and consequently of an average uniform speed of current. We will assume, further, that the density of the air is also constant, the variations of pressure, taking into account the total atmospheric pressure, being so small as to be almost insensible. At A we should have a pres-

* A pressure of 1 kilo per square meter is equivalent to 0.205 pounds per square foot.

sure H, at B a lower pressure H', and the difference $H-H'$ would be the exact loss of head h we were looking for.

The effort exerted at A in the direction of the movement will be equal to sH, in which s represents the average cross-section of the gangway. The counter-effort, or resistance at B, will be sH', and consequently the resulting motive-power will be the difference $sH - sH' = sh$.

The resistance to be overcome is, as we have said, proportional to the extent of the frictional surface exposed; that is to say, to the product, Lp, of the length of the gangway by its perimeter. It is

Fig. 1.

HYPOTHETICAL MINE-GANGWAY

likewise proportional to the density, or, to be more precise, to the weight, δ, of the cubic meter of the air in circulation, to the square of its average speed, v, and lastly to a coefficient, x, whose numerical value varies according to the nature of the sides of the gangway and the irregularities of its course.

By combining the power and the resistance thus defined, we obtain the equation

$$sh = xLpv^2\delta,$$

from which we may deduce

$$h = x\frac{Lpv^2\delta}{s},$$

which expresses the loss of head for a given length L of the passage under consideration.

Some authors, and particularly Mr. Devillez, in reproducing this formula, have disregarded the specific weight δ, probably having considered that, in practice, the variations of atmospheric density amount to very little compared to the uncertainty of the numerical value of x in each individual case. In order to accept this very judicious remark, which permits us to economize both in observations and calculations, we can replace in the preceding equation the specific weight δ by the ratio $\frac{\delta}{\delta_0}$, in which δ_0 represents the usual aver-

age specific weight of air in mine-workings; for example, 1.2 kilogrammes. We then have:

$$h = x \frac{Lpv^2\delta}{s\delta_0}.$$

If we wish to neglect the variations *plus* or *minus*, which may occur in the density of the air, it will be sufficient to assume $\delta = \delta_0$, and thus we revert to the simpler formula of Mr. Devillez:

$$h = x \frac{Lpv^2}{s}.$$

We can assume the general expression of the loss of head as an equation of which the unknown quantity is x. In resolving it with respect to this quantity, we obtain

$$x = \frac{hs\delta_0}{Lpv^2\delta},$$

which expression shows that if we can determine by direct observation the loss of head, the length of the passage, its average section, its average interior dimensions, the average speed of the air and its specific gravity, we shall be in position to deduce the numerical value of the coefficient x.

The object of this paper is precisely the determination of this numerical value for three well-defined types of gangways, viz.:

Gangways in solid rock, unlined.

Gangways lined with masonry.

Gangways timbered.

The present investigations are not by any means the first which have been undertaken on this interesting subject. More or less successful experiments have been carried on at various times, and it is our duty to mention them here. During many years, mine-operators had at their disposal only figures deduced from the antiquated experiments of d'Aubuisson and Navier on the flow of air through pipes. According to the former we should have, $x = 0.00037$,* and according to the latter, $x = 0.000355$.

Naturally, these values could be applied only with great caution to the case of underground workings, because of the relative importance of the section of these new conduits, and of the particular

* These figures and the ones following are quoted from Mr. Haton de la Goupillière's *Cours d'Exploitation des Mines*, vol. ii., p. 389.

characteristics of their interior surfaces. It was to obviate this uncertainty that, in 1866, Mr. Devillez undertook the remarkable experiments which he has described in the first pages of his treatise on *Ventilation des Mines.*

Mr. Devillez looked for and easily found in the mines of Hainault long circuits formed by gangways, which were continuous from end to end and returned very nearly to their point of departure. At this latter point the dividing partition was pierced, and one of the legs of a water-gauge passed through. A more or less violent circulation of air being started in the circuit, the water-gauge registered the total loss of head, h; and as, on the other hand, the circuit was divided up in sections of nearly equal length, in each of which the values L, s, p, and v were determined, all the necessary data were obtained to calculate the average value of the coefficient x.

Thus, Mr. Devillez obtained, as a result of three corroborative experiments, the value, $x = 0.00180$.

This important determination rendered a real service to mine-operators; but, I must repeat, it represents only an average, and does not take into account the variations which would occur in the various sections, caused by their departure from a straight course and by the surface-irregularities of their sides. *A priori*, therefore, it seems evident that very great variations must occur between one gangway and another, and particularly between the three types that we have defined above. From experiments in England, Mr. Atkinson found, $x = 0.00410$, and Mr. Clark found, $x = 0.00043$. These last values vary very much, both above and below those proposed by Mr. Devillez, without one's being able clearly to determine the reason, and therefore I may be permitted to say, without wishing to belittle the work of my predecessors, that this interesting question of the determination of the loss of pressure in underground air-ways is far from having been made in a complete manner, and that an extensive field for investigation remains open to engineers desirous of following up the several lines of research.

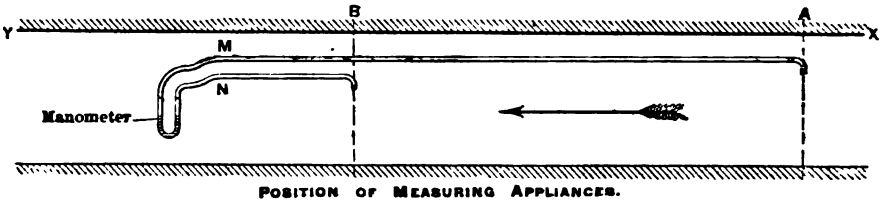
It is in this unthankful field that we entered by the laborious and difficult investigations which we detail to-day, and although we have been able to penetrate only a short distance into it, we believe, to say the least, that we have exercised sufficient care and perseverance to insure our results from error and to place them beyond dispute.

II. Method of Observation and Appliances for Testing.

Description of the Method.—The method which we applied to de-

termine the loss of head can be briefly described. Let XY (Fig. 2) be the gangway, assumed to be horizontal, to begin with, and of approximately uniform cross-section, in which the air moves in the direction of the arrow. Starting from the same vertical plane, MN, two lines of pipe are laid along the walls, one being very long and the other quite short, so as to allow a distance of about 100 meters between their open ends, A and B. The opposite ends, M and N, are connected by rubber tubing with the two limbs of an ordinary gauge, formed by a U-shaped tube half filled with water. The stagnant air filling the pipes will transmit to the gauge the pressures at the open ends, A and B, more or less modified by the disturbing action due to the impact or suction of the air on the open ends of the pipes. But as this action, exerted under identical conditions at A and B, is equal for the two parts and self-compensating, the difference of water-level in the gauge will be the exact measure of the

Fig. 2.



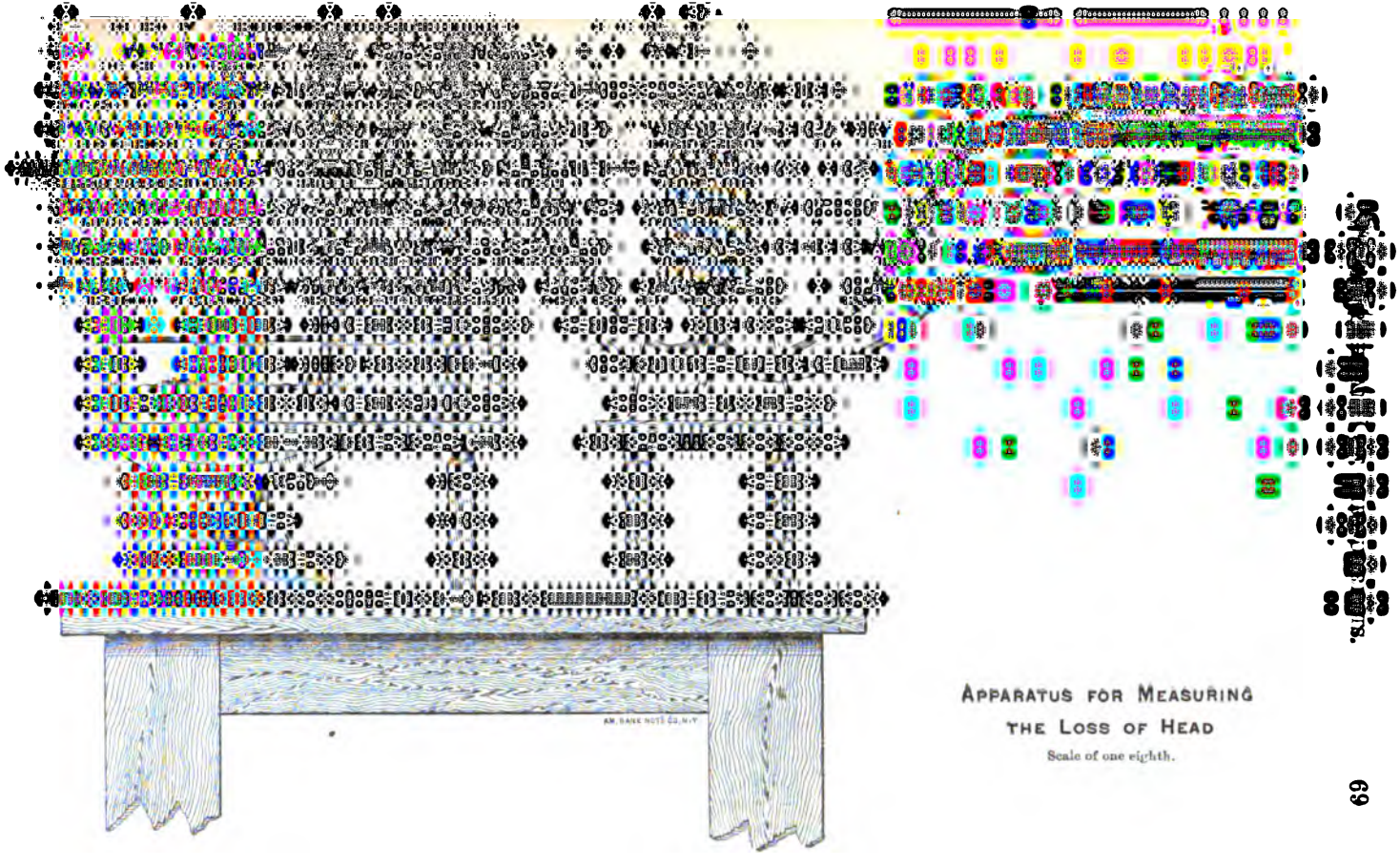
POSITION OF MEASURING APPLIANCES.

difference of pressure at the points A and B; that is to say, of the loss of head due to the circulation of air over the course from A to B. The result would be the same if the gangway were inclined instead of horizontal, since the column of air in circulation and the columns filling the pipes have the same pressure and same temperature, and hence balance one another in the gauge without disturbing the indicated results.

Now if, simultaneously with the observation of the loss of head, we take anemometric measurements, accompanied with the usual observations as to temperature, atmospheric pressure and humidity, and if care has been previously taken to measure the distance AB and the average section and average internal surface, we shall be in position to substitute figures for the symbols of the formula,

$$x = \frac{hs\delta_0}{Lpv^2\delta},$$

and, consequently, to calculate the numerical value of the coefficient x.



APPARATUS FOR MEASURING
THE LOSS OF HEAD

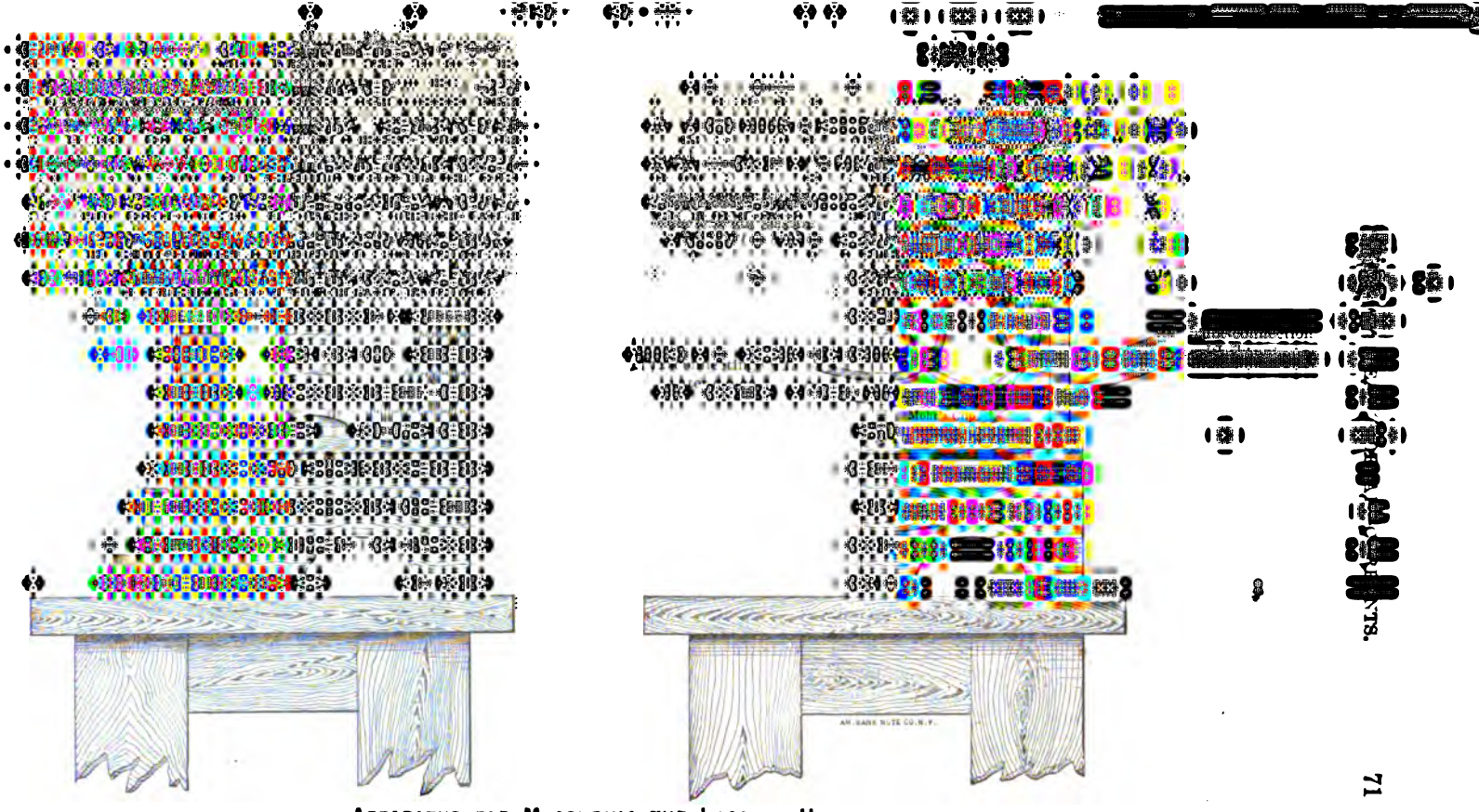
Scale of one eighth.

From the simplicity of the principle, however, to the difficulties of its practical application there is quite an interval, as may be judged by the description we shall give of our appliances and methods of operation.

Piping.—Our tubes were formed of ordinary commercial iron pipe, with screw-joints. Their inside diameter was 27 mm. They were flexible enough to follow the bends of the gangways. The open ends *A* and *B* were terminated with a right-angle elbow, the opening of which was brought near the wall and protected by a small screen against the impact of the air. As a fact, we did not have a very clear idea of the best arrangement to provide for these pressure-intakes. We were satisfied to admit that the disturbing elements at the two extremities *A* and *B* of the line would compensate one another accurately enough not to spoil our observations.

The ends *M* and *N* were fitted with reducers of small diameter, over which were fixed the rubber tubes which communicated with the gauge. All joints were covered with cement, and no observations were begun until we were certain that the pipe-line and other instruments were absolutely air-tight. For simplicity, we have always designated the distance *AB* as the *course*, and we shall continue to use this designation in this paper.

Water-Gauge.—The chief requisite to the success of our experiments was the possession of a differential gauge of the most minute delicacy. We foresaw that the losses of head would often hardly exceed a fraction of a millimeter of water, and under these conditions our measurements would have been valueless, unless they were exceptionally accurate. There are in the market many types of differential, multiplying water-gauges, but generally the enlargement of gauge is obtained by mechanical appliances, which offer a certain resistance, and a consequent diminution in sensitiveness. This is made apparent when the equilibrium is re-established in the instrument, by the sluggishness with which the needle returns to the zero-mark. This is why we adopted the old-fashioned U-tube, in which the gauging liquid is free to balance all pressures which affect it, a microscope being the only means we used for magnifying the readings. The two limbs of the U-tube were formed by two flasks accurately gauged, of equal height but very unequal diameter, connected below by a rubber tube and half filled with water. (Figs. 3, 4, 5.) The upper orifices were closed by corks, through each of which passed a glass tube, and each cork was pressed far enough down in



APPARATUS FOR MEASURING THE LOSS OF HEAD.
Scale of one eighth.

the neck of its flask to form a sort of cup in the upper part of the neck, which was filled with water. The rubber tubes which formed the connection to the pipe-line were pushed down into these water-seals, and so assured perfectly tight joints, which is the essential condition to the success of the experiment. A sort of wooden frame fixed round the neck of the wide flask served to support these tubes.

Owing to the difference in the diameters, nearly the whole variations of level took place in the thin flask on which our readings were taken; and having once for all determined the ratio, it only remained to increase these readings by that ratio in order to determine the lowering of the level in the wide flask. The internal diameter of the small flask was 50 mm., and that of the wide one 163 mm. The ratio of increase actually measured in three corroborative tests was equal, 1.0960.

Opposite and nearly touching the small flask was placed a microscope with cross-hairs, magnifying 50 times, and mounted on a sliding pedestal or cathetometer, which we shall describe presently. One essential requirement was to render clearly visible to the microscope the base of the meniscus formed by the contact of the water with the glass. We succeeded by means of the following device: On a black surface placed behind the flasks, a white line was traced below the water-level by means of a glass tube filled with paint. This tube, brilliantly illumined by a Marsaut lamp, was reflected entirely at the base of the meniscus in the shape of a thin, brilliant line, on which we could, without hesitation, train the cross-hairs of the eye-piece.*

For the measurements of the vertical motion of the microscope, we could have made use of the system of micrometer screws applied to the laboratory cathetometers; but for the sake of simplicity of construction and facility of readings we were led to adopt a different arrangement. The microscope is clamped to a gudgeon, which revolves in a block mounted on a strong sliding pedestal. This gudgeon carries on its end a needle or graduated pointer 240 mm. long, the end of which moves on a horizontal graduated arc. The axis of the microscope does not coincide with that of the gudgeon, it being

* By rights, this white line ought to have been movable up and down with the eye piece itself, in order always to maintain the same inclination to the incident ray of light; but with the minute variations of level that we were called upon to observe, the error due to this cause was imperceptible.

6 mm. out of center in a horizontal direction; consequently, when the graduated pointer describes a horizontal arc from left to right, the cross hairs of the eye-piece describe an ascending vertical arc forty times smaller.

To adjust the instrument, the pressures are first equalized in both limbs of the gauge. The pointer is pushed back to the zero-mark on the horizontal scale, and the microscope is raised to the water-level by means of the thumb screw placed at the base of the slide. Connection being then established in proper form between the pipe-lines and the gauge, the water will rise in the narrow flask, and all that is required is to move the vernier from left to right on the gauge to cause the microscope to follow the rise of the water-level, and so be able to read the variation on a scale forty times magnified. The graduation of the arc in degrees and minutes does not give the height of the column of water directly, but rather a trigonometric function of it, which is a very close approximation. It is, therefore, requisite to make a preliminary comparative measurement, which is done by substituting for the small flask a scale divided in half-millimeters, and then by means of the thumb-screw, taking an exact reading for each of these divisions. Transferring these graphically to paper, the arc readings in abscissas, and the heights in ordinates, we obtain an abacus which permits us to pass from one graduation to the other with great ease.* The arc only allowed measurements of less than 6.5 mm. For greater variations we could have used as a micrometer the thumb-screw at the base of the slide, the pitch of which was exactly 1.32 mm. As a fact, the necessity for this never occurred.

Thanks to our arrangements, and especially to the device of the *white line* which really was the only novelty we introduced into our system of observation, we succeeded in turning the primitive water-gauge into an instrument of really remarkable sensitiveness. Provided it is placed on a solid foundation, such as a block of masonry, it would be possible to register a rise in the water-column of $\frac{1}{100}$ mm. Underground, where absolute stability was not always practicable, we generally succeeded to $\frac{1}{50}$ of a millimeter. As an illustration of the extreme sensitiveness of the instrument, it was only necessary for one of our assistants to enter the gangway under observation for his

* It would not be impossible, with the data obtained, to determine the constants of a formula of transformation, but the graphical method is quicker and fully as exact.

presence to be immediately detected by a slight rise of the white line, due to the increased friction and consequent loss of head.

Hydraulic Valves.—The rubber tubes connecting the gauge with the line-pipes were fitted with hydraulic valves, so as to allow a quick substitution of the surrounding atmospheric pressure for the pressures to be observed. This was necessary to permit an adjustment of the zero of the instrument before and after each observation. The fear of leakage in the ordinary three-way cocks determined us to use the hydraulic valves shown in Figs. 3 and 5. Through the bottom of a small zinc tub, half full of water, pass four vertical tubes, which are covered, two and two, by small floating bells. The lower ends of these four tubes are connected by rubber tubes on the one side to the two branches of the water-gauge, and on the other side to the pipe-lines, so that it is evident that the gauge is in connection either with the pipe-line pressure, or with the atmosphere surrounding the instruments, depending on whether the bells are lowered or raised. A fifth tube, opening under one of the bells and closed by a Mohr clip, served to test the air-tightness of the whole system by blowing air in after having first stopped up the free ends of the pipes and observing the steadiness of the water-column in the gauge by aid of the microscope.

Anemometers.—As previously observed, each observation had to be accompanied with anemometric measurements. For this purpose we used the small wing-anemometers made by Casartelli, of Manchester. As these instruments are very sensitive, and yet well protected from the rough usage inseparable from their employment in underground workings, they were well adapted for our purposes. Thanks to the courtesy of our friends, we had four of these instruments at our disposal. We gauged them with every possible care by means of a turntable which we fitted up in our workshop, and to prevent any possible confusion in the use of the coefficient determined for each we painted large letters, A, B, C, D, on their respective base-plates. In the mine, these instruments were placed on horizontal wooden straight-edges cut to a knife-edge on the front, so as to cut the air-currents without disturbing them (Fig. 6). At each position two little stud-pins, corresponding to two holes bored in the base-plate of the instruments, permitted them to be set up instantly and without hesitation. We know that the air-velocities are distributed in a very irregular way through the section of mine-gangway, as may be seen by the diagrams which accompany this paper. It was, therefore, necessary to multiply the number of points of ob-

...with any degree of ...hese observation- ...portance of the sec- ...r 5 straight-edges. ...C, D from left to ... reading. The ob- ...was the time that ...certainties due to ...s with four instru- ...ng did not exceed ...his could evidently ...of head, which we

... The presence, too, ...servation, would, as ...rror. The general ...mination of each ex- ...s, placed at random ...company the read- ... of these was made. ...e made had proved ...t modify the curves ...he air-velocities at ...rease or decrease as ...ues. Hence, to ob- ...angway it is suffi- ...s section, provided, ...hese two velocities

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...es, vol. ii., p. 397.

By taking four points instead of one, the accuracy of the application of this theorem was greatly increased.

Our first work, therefore, on our return to the office, was, after calculating all the velocities of the section under consideration, to establish separately the general average of these velocities and the average of those observed at the four chosen points. Thus we established the coefficient of correction to be applied to the average of the observed velocities at these same points during the readings for the loss of head, in order to compare this average with that which really existed in the whole gangway.

Atmospheric Observations.—A thermometer graduated in tenths of a degree, a Fortin barometer,* and one of Saussure's hair hygrometers furnished us all the data required to determine the weight of the cubic meter of air in motion.

I must say that the hair hygrometer did not inspire us with much confidence. It is not a reliable instrument, and several times we had to correct its registerings.

Choice of Location.—The field of investigation which we had to traverse might be regarded as almost boundless, from the fact that underground passages offer an infinity of different types, whether we consider their direction, their profile, or their lining. As we had to keep within limits, we fixed the number of our experiments at twelve, dividing them between the three well-defined types already mentioned—gangways without lining, those lined with masonry, and those lined with timber.

In our mines at Bessèges we experienced some difficulty in finding sections of gangways correctly answering this programme; that is to say, presenting a sufficient regularity both of cross-section and of character of sides, on a sufficient length of course to insure accuracy of observation. This length we fixed first at 100 meters for a minimum, but we were obliged to vary from this fixed length and to come down, in one of our experiments, even to 61.30 meters. It was requisite, moreover, that the course should be completely isolated from the rest of the workings, so as to give rise to no disturbing entries or exits of air; lastly, it was necessary to be in position, by opening or closing of brattice-doors, to produce in the section under experiment a circulation of the air, which should be sufficiently active to ensure a practical figure for the loss of head. This last

* We began by using two aneroids carefully adjusted to our Fortin, and which were less clumsy, but we had to reject them, owing to variations in their registerings.

requirement caused us a good deal of trouble. It is much more difficult than it appears at first sight, to divert an air-current from its accustomed course; the bratticings, the gobbins, even the masonry-linings are seldom air-tight, and losses of air occur where they are least expected, and, finally, much lower velocities are realized than those hoped for.

Thanks to the sensitiveness of our gauge, however, these drawbacks did not prevent our measuring the loss of head with sufficient accuracy to serve as a correct basis on which to make our calculations and deductions.

We shall describe the twelve courses when we come to record results of our observations in them.

Manner of Procedure.—All of our observations were made at night or on Sunday mornings, these being the only times when, owing to the cessation of work, it was possible to have control of the air-currents of a mine. One of our mechanics placed the pipes, and also the straight-edges and instruments in position during the day. Notwithstanding the fact that theoretically it is immaterial whether the instruments be placed at the head or tail of the air-current, we found it more convenient to place them at the latter, and that was the rule we adopted. Immediately after the exit of the miners, the timbermen arranged the brattices, which were to increase the circulation of the air over the course, and when we reached the place at eight o'clock everything was ready to commence operations. While one of the observers tested the tightness of the pipe-joints and apparatus,* adjusted the zero of the water-gauge, and made the atmospheric observations, another with his assistants measured the length of the course, and took exact measurements every 10 meters of the cross-section of the gangway.

These preliminaries being completed, the four anemometers were placed at any four points in the section to be gauged, and at a given signal they were started simultaneously with a second-counter. Without loss of time, ten consecutive readings for the loss of head were made, a reading being taken every quarter of a minute, and immediately afterward the counter and anemometers were stopped. This operation was repeated twice, often three times, and in one special experiment even six times; after which nothing remained to be done except the general gauging of the course under the condi-

* Frequently the perfect tightness of these joints was secured only after several hours of work, and especially was this the case at the start.

tions described above. The same operations were always performed by the same persons, with the same instruments, and all the readings were confirmed by a second observer.

Each experiment furnished material for a long series of calculations, the results of which are shown on the diagrams herewith. One of these calculations was especially complicated, viz.: the one required to establish the average velocity of the gaugings. The simple arithmetical average of the observed velocities appearing to us insufficient for accuracy, we adopted the method of determining the volume of the solid conical cylinder defined by the curves of equal velocity (Figs. 7 to 20); this volume was evidently equal to the discharge, and by dividing it by the area of the section of gauging, we obtained the geometric average of the velocity with every possible accuracy.

Notwithstanding all our precautions, we could not guard our observations against one serious source of error, due to the fact, first published in 1877 by the Commission on Ventilation of the Gard, and since verified and confirmed by the Prussian Fire-Damp Commission, that paddle-anemometers calibrated on a turntable, are apt to give exaggerated values for the velocities which they measure. One has to admit as a fact, that for a given relative velocity, the anemometer will revolve faster when it receives the impact of the air, in a stationary condition, than it does when put in motion itself through the air on the arms of a turntable. This is not the place to discuss this seeming paradox; it will suffice to remark that this excessive registry which increases with the velocity of the air, can reach 10 per cent. with velocities of 6 meters per second.

To obviate this error, we ought to have been in position to adjust our anemometers by means of a volumetric apparatus, a gasometer, for example, as was done by Mr. Althans, at Breslau; but this means was not at our disposal. It appeared to us, too, that since all the daily tests taken in mines, were made with anemometers calibrated on a turntable, it was quite as well to base the numerical coefficients that we were going to deduce from our experiments on the same system of observation, even though it were incorrect, so as to allow comparisons between them, and to facilitate their application.

Before giving the results of our experiments, we wish to express our sincere thanks to the gentlemen whose generous assistance assured our success, especially to the directors of the Bessèges Colliery Company, who furnished both the necessary time and money. Then also to our loyal collaborators, whose zeal was not abated an instant,

notwithstanding the particularly disagreeable physical conditions under which they had to operate, Mr. Francis Dubost, our colleague at the Bessèges mines; Mr. Simeon Moulin, the surveyor, and his assistant, young Gaston Agniel.*

III. The Ratio of the Loss of Head to the Square of the Average Velocity.

In giving the formula of the loss of head in mine-passages,

$$h = x \frac{Lpv^2\delta}{8\delta_0},$$

we accepted as self-evident or as demonstrated, all the laws of ratio which it implies. At the same time, one of them raised a serious doubt in our mind, viz.: the law which makes the loss of head increase as the square of the average velocity of the air. Nearly all authors who have given attention to the flow of fluids in different kinds of conduits, have recognized that this ratio ceased to be exact for low velocities, and have been led to introduce in the formula for the loss of head either a term of the first degree (Coulomb, de Prony, d'Aubuisson, Darcy, Arson):

$$h = a v + bv^2,$$

or an exponent below the square (de Saint-Venant, Reynolds, Flamant),

$$h = cv^{(2-)}$$

On the other hand, Mr. Rateau, Professor in the School of Mines at St. Étienne, has described an experiment made at the Montrambert mines,† not on a section of any one passage, but on the whole mine, where the loss of initial pressure of the ventilation increased as the 1.75th power of the discharge. It was important, therefore, that at the outset we should satisfy ourselves on this point, and to that end, in two of our experiments, we multiplied the number of our obser-

* Although the number of our tests was only twelve, fifteen sittings were required to give our work the necessary exactness. Our first experiment had to be repeated, owing to errors due to our inexperience at the outset. The second was repeated because we thought it incorrect, when, in reality, it was perfect; and lastly, one of our gauging-tests had to be repeated because the distribution of velocities seemed to us abnormal. Those fifteen sessions occupied the whole month of November, and the beginning of December, at the rate of three weekly.

† *Bulletin de la Société de l'Industrie Minérale*, vol. vi., 3d. series, 1892, p. 133.

vations on the loss of head, varying each time the value of the average velocity.

The first of these experiments was carried out in a main entry, timbered with square oak, according to the usual method in the mines of the Gard (see page 100, *Exp.* 10). The sets, each composed of two posts and a cap-piece, are spaced on an average 0.90 meter from center to center, and the spaces between the sets are backed with round poles. The average height under the cap is 1.85 meters, the width at the roof is 1.20 meters, and on the floor 2.10 meters. This entry is very old, and owing to the repairs made from time to time, the profile presents numerous irregularities. This was a favorable condition for producing a high loss of head. The course, slightly irregular but generally straight, was 97.08 meters long. It was in the vicinity of the Créal fan, which enabled us to obtain high air-velocities. A brattice-door which could be opened by degrees furnished an easy method of graduating the velocities from zero to the maximum. Our observations, six in number, are reproduced in the following table, in which for purposes of comparison the calculated loss of head is also given, being figured on the hypothesis of its exact ratio to the square of the average velocity, that is to say figured on the formula:

$$h = cv^2,$$

in which c has the average value given by the last four experiments.

No. of Experiment.	Average Velocities.		Loss of Head.		Difference.
	v.	v^2.	Observed.	Calculated.	
	M.	M.	Mm.	Mm.	Mm.
1	0.926	0.858	0.36	0.32	— 0.04
2	1.327	1.762	0.70	0.66	— 0.04
3	2.153	4.638	1.76	1.73	— 0.03
4	2.981	8.890	3.34	3.31	— 0.03
5	3.655	13.355	4.96	4.98	+ 0.02
6	4.202	17.658	6.53	6.58	+ 0.05

The variations are only a few hundredths of a millimeter plus or minus, and therefore we may well be permitted to assume that the formula is sufficiently accurate for general application.

But the accuracy of our results permits the question being followed still closer. It is easy to recognize in fact, by the direction and extent of the differences, that a similar influence to that observed by the above-quoted authorities is exercised over the variations of the loss of head. If we accept Flamant's simple formula, a close analysis of our observations would lead us to replace the square of the average velocity, by the 1.9267th power:

$$h = \alpha v^{1.9267}.$$

Under this assumption the differences dwindle in a marked degree, especially for the lower velocities, as can be seen by the following new table:

No. of Experiment.	Loss of Head.		Difference.
	Observed.	Calculated.	
	Mm.	Mm.	Mm.
1	0.36	0.35	— 0.01
2	0.70	0.71	+ 0.01
3	1.76	1.79	+ 0.03
4	3.34	3.36	+ 0.02
5	4.96	4.97	+ 0.01
6	6.53	6.51	— 0.02

Let us hasten to add, though, that these new results differ too slightly from the first ones to invalidate to any appreciable degree for mining practice, the law of the ratio to the square of the velocity.

Our second experiment was made in a main gangway arched over with masonry, the dimensions being, height, 2 meters, and an average width of 1.95 m (see page 90, *Exp.* 5). The length of the course under observation was 110.9 meters, and straight. This gangway served as main air-way for the Créal mine, and we were therefore able to obtain air-velocities of 5 to 6 meters a second, being by far the strongest we were able to observe during all our experiments. Nevertheless the loss of head was minimized by the smoothness of the brick walls and roof, lubricated even by that greasy deposit which is always present on the surfaces in return air-ways. Still, by means of a door opened gradually, we were able to make

four observations of increasing intensities, the results of which are condensed in the following table:

No. of Experiment.	Average Velocities.		Losses of Head.		Differences.
	v.	v^2.	Observed.	Calculated.	
	M.	M.	Mm.	Mm.	Mm.
1	2.368	5.607	0.37	0.38	+ 0.01
2	3.522	12.407	0.84	0.84	0.00
3	4.375	19.144	1.29	1.30	+ 0.01
4	5.236	27.413	1.87	1.86	— 0.01

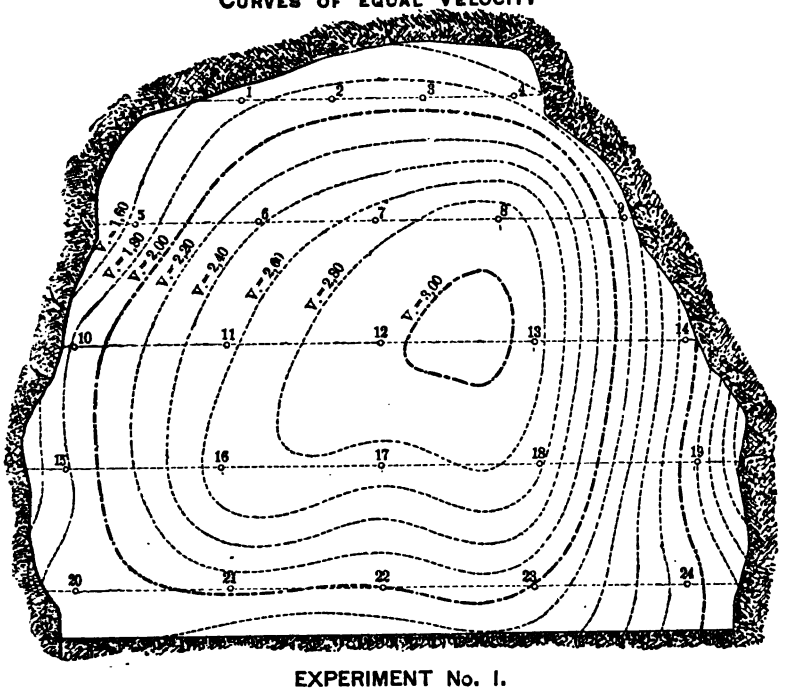
In this table the ratio of loss of head to the square of the velocity is made very apparent. Evidently the small number and minute readings for the loss of head would prevent us from asserting that no similar influence exists to that discovered by our first experiment. But that is immaterial, and for the practical end we have in view it is sufficient that the corroborative results of our two experiments authorize the statement that the law of ratio to the square of the velocity is sufficiently exact to serve as a sound basis for the calculation of the loss of head in underground works. These first results were such as to inspire us with great confidence in the correctness of our methods of observation. They give in advance an actual authority to the numerical values which we are about to deduce as the result of our researches for the coefficient x of the loss of head.

As we announced at the outset of this paper, our experiments will be grouped in three divisions, according to the character of the gangways in which they were made, and we shall study them in the following order: (1) Rock gangways, (2) those lined with brick, and (3) those timbered with square sets.

IV. Gangways in Plain Rock.

Experiment No. 1.—The first experiment was made in a rock cross-cut, in the first level of the Créal mine, of the usual dimensions of our main gangways, viz., a height above the rail of 1.90 to 2.00 meters, and about the same width. We shall designate this hereafter as the *normal* gangway. The course was perfectly straight, and measured 93.87 meters in length. The section was fairly regu-

Fig. 7.
CURVES OF EQUAL VELOCITY



EXPERIMENT No. I.

(November 17th, 1892.)

Rock Gangway, Normal Section.

CRÉAL MINE—FIRST LEVEL.

SCALE IN FEET AND METERS.

0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 Meters.

In. 12 9 6 3 0 1 2 Feet

VELOCITIES OBSERVED.

No.	Meters	No.	Meters	No.	Meters
1	1.787	9	1.749	17	2.706
2	1.911	10	1.815	18	2.673
3	1.975	11	2 553	19	0.735
4	1.724	12	2.560	20	1.880
5	1.631	13	2.897	21	2 006
6	2.397	14	1.122	22	2 011
7	2.635	15	1.757	23	1 983
8	2 922	16	2.728	24	1.090

Average Velocity	meters,	2.168
Area of Gangway	sq. meters,	3.7045
Volume Discharged	cub. meters,	8.031
Maximum Velocity	meters,	3.040
Ratio of Maximum to Average Velocity		1.401

lar, but some blocks having fallen from the roof had left a few fair-sized recesses overhead. (Fig. 7.)

The principal data and the results of this experiment are summed up in the following table. The observations for the average velocity and the loss of head were duplicated as in all the succeeding experiments; the weight of the cubic meter of air has been reduced everywhere, in the calculation of the coefficient x, to the uniform standard of 1.2 kilogrammes.

Length of course,	93.87 meters.
Average area of cross-section,	3.5840 sq. meters.
Average perimeter,	7.40 meters.
Weight of one cubic meter of air,	1.183 kilogrammes.
Average velocity,	2.3 meters and 2.284 meters.
Loss of head,	0.93 mm. and 0.91 mm.
$x =$	.0.00092 and 0 00091
Average value of x,	0.00092

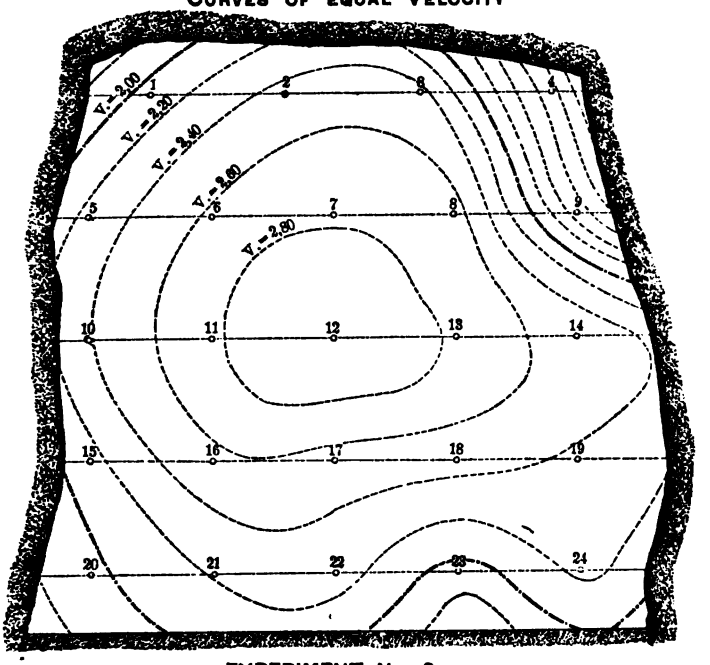
The velocity was rather small, and consequently the loss of head slight; so much so that we felt the necessity of verifying the first results by a second observation made in a drift of the same character.

Experiment No. 2.—We selected a cross-entry of the fourth level of the Créal mine, also *normal*, but having a slightly increased average cross-section of 4.13 sq. m., instead of 3.58 sq. m. (Fig. 8.)

This cross-cut, which was perfectly straight, had been driven with power-drills through very compact sandstone. As is seen on the cut, the roof is much squarer than is generally the case in hand-driven tunnels. Although the cross-section was not absolutely constant, the surfaces were very regular and presented no very rough places. It was here that we at first supposed the experiment to have been incorrectly made (see footnote, p. 79). We found it impossible to obtain a higher average velocity than 2 meters, and as the course laid out was short (76.35 meters), the loss of head was barely more than one-half a millimeter. Nevertheless, owing to the accuracy of our instruments, the results of this experiment are fully as reliable as those obtained elsewhere.

Length of course,	76.35 meters.
Average area of cross-section,	4.1300 sq. meters.
Average perimeter,	8.02 meters.
Weight of one cubic meter of air,	1.245 kilogrammes.
Average velocity,	2.038 meters and 2.086 meters.
Loss of head,	0.56 mm. and 0.57 mm.
$x =$	0.00087 and 0.00085
Average value of x,	0.00086

Fig. 8.
CURVES OF EQUAL VELOCITY



EXPERIMENT No. 2.

(November 27th, 1892.)

Rock Gangway, Normal Section.

CRÉAL MINE—FOURTH LEVEL.

SCALE IN FEET AND METERS.

0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 Meters.

In. 12 9 6 3 0 1 2 Feet

VELOCITIES OBSERVED.

No.	Meters	No.	Meters	No.	Meters
1	2.065	9	1.509	17	2.504
2	2.455	10	2.388	18	2.426
3	2.446	11	2.770	19	2.319
4	1.262	12	2.962	20	1.957
5	2.240	13	2.749	21	2 219
6	2.621	14	2.534	22	2.285
7	2.768	15	2.084	23	1.957
8	2.689	16	2.569	24	2.213

Average Velocity	meters,	2.377
Area of Gangway	sq. meters,	3.5683
Volume Discharged	cub. meters,	8.482

Maximum Velocity	meters,	2.970
Ratio of Maximum to Average Velocity		1.249

The slight decline of the coefficient of the loss of head in this drift can only be explained by the greater smoothness of the roof and walls. An examination of the curves of equal velocities shows that the retardation at the sides is appreciably less than in the preceding experiment.

Experiment No. 3.—From the above location we moved to a magnificent cross-cut, absolutely straight, on the fourth level of the Bessèges mine. Its dimensions were 3 meters to 3.20 meters wide by 2 meters high. We were able to maintain an average velocity of 2.40 meters, which was better than we had expected, owing to the distance from the fan and the large cross-section of the drift. (Fig. 9.)

Length of course,	94.70 meters.
Average area of cross-section,	5.8160 sq. meters.
Average perimeter,	9.77 meters.
Weight of one cubic meter of air,	1.265 kilogrammes.
Average velocity,	2.425 meters and 2 248 meters.
Loss of head,	1.03 mm. and 0.89 mm.
$x =$	0.00104 and 0.00105
Average value of x,	0.00104

We were surprised at this comparatively high result. From preconceived ideas, supported by the observations of many authors, we had supposed that the loss of head diminished more rapidly in passing from one passage to a wider one, than the ratio of the perimeter to the cross-sectional area—or, in other terms, that the coefficient x diminished as the widths increased. The opposite occurs in reality, without any seeming reason for it. It may be that we must acknowledge that the retardations, due to the impinging of the current on the alternating inclined strata of hard and soft rock, are relatively increased in wide gangways, but this alone would not explain it. The real cause appears to be indicated by the diagram of the curves of equal velocities, in which the greatest velocities appear near the right-hand wall instead of in the center of the passage, as in most other cases.* This resulted in an excess of friction, which would necessarily betray itself in an increase of the coefficient x. However, this increase is only trifling, and cannot be considered as militating against our results.

* A few meters beyond the measured course the air-current was deflected at an angle of 90° to the right, to enter the workings of the St. Emile bed and to reach the fan. It is possible that it was this side-pull which induced the higher velocities near the right-hand wall.

EXPERIMENT No. 3.

(November 29th, 1892.)

Rock Gangway, Large Section.

BESSÈGES MINE—FOURTH LEVEL.

SCALE IN FEET AND METERS.

0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 Meters.

1a.12 9 6 3 0 1 2 Feet

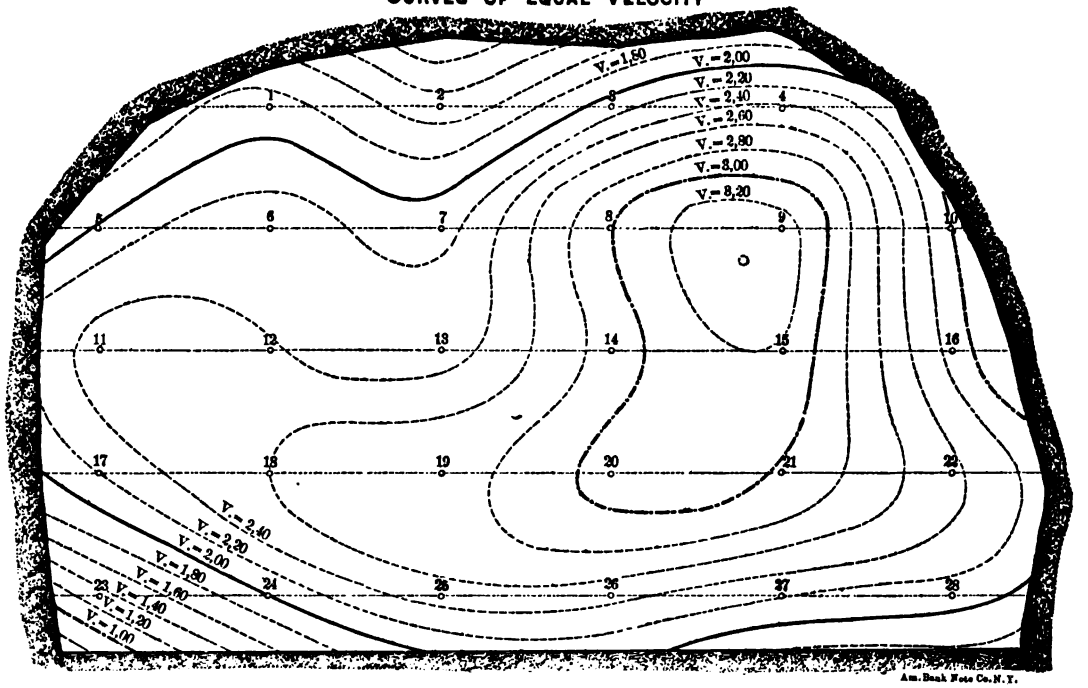
VELOCITIES OBSERVED.

No.	Meters	No.	Meters
1	1.869	15	3.165
2	1.497	16	2.132
3	2.102	17	2.207
4	2.422	18	2.609
5	2.018	19	2.749
6	2.295	20	3.061
7	2.138	21	2 978
8	2 988	22	2.437
9	3.266	23	1.307
10	1.974	24	2.016
11	2.461	25	2 511
12	2.413	26	2.487
13	2.323	27	2.221
14	2.884	28	2.092

Average Velocity	meters,	2.401
Area of Gangway	sq meters,	5.8821
Volume Discharged	cub. meters,	14.123
Maximum Velocity	meters,	3 340
Ratio of Maximum to Average Velocity		1.391

Fig. 9.

CURVES OF EQUAL VELOCITY



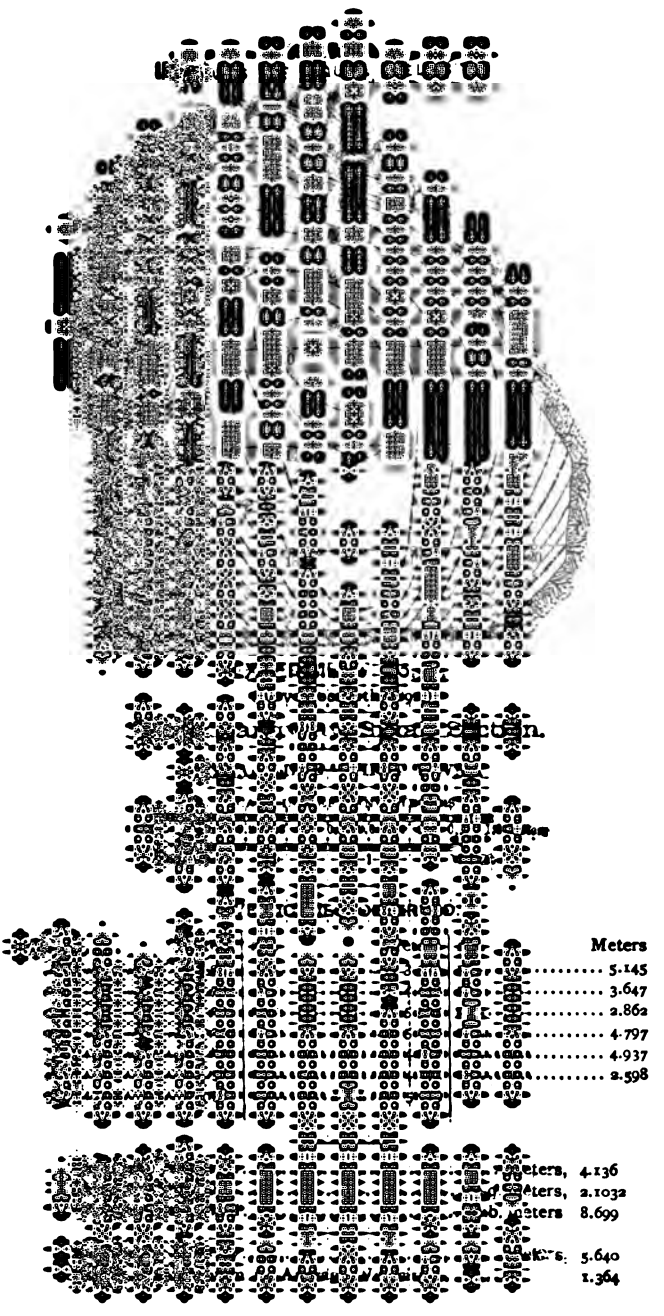
Experiment No. 4.—We determined to make this fourth and last of the experiments on rock-cut gangways, on one of small cross-sectional area. The type we selected was an inclined cross-cut, 1.70 meters high by 1.20 meters wide, which connected the 1st and 2d levels of the Bessèges mine, and served as a passage-way to the Créal workings. The grade was 0.40 meter per meter; steps of oak-wood fastened to the floor aided the ascent. The general direction was straight, but with one or two local deviations. The cross-sectional area averaged, pretty regularly, 2 square meters, but as this uprise had been driven on a very faulty seam, it had resulted in a very irregular profile, as can be seen by reference to Fig. 10. This condition, added to the irregularity of the floor, due to the steps laid upon it, prepared us for an appreciable increase in the coefficient of loss of head, which was also verified by the experiment.

We were able to obtain high air-velocities, a much easier problem, with passages of small cross-section than with larger gangways.

Length of course,	75.20 meters.
Average area of cross-section,	2.0220 sq. meters.
Average perimeter,	5.39 meters.
Weight of one cubic meter of air,	1.201 kilogrammes.
Average velocity,	4.173 meters and 4.309 meters.
Loss of head,	4.24 mm. and 4.56 mm.
$x =$	0.00121 and 0.00122
Average value of x,	0.00122

As we have just said, the decided increase here in the coefficient of loss of head was not a surprise to us; yet we do not think that the irregularities and roughness of the course were the sole cause of it. Notwithstanding that experiment No. 3 did not confirm our theory, we continue to believe that, everything else being equal, the coefficient of loss of head varies slightly with the section of the passages under observation, lessening for wide openings and increasing for narrow passages. The decrease may be almost insensible in passing from a normal gangway to a wide one, but the increase, on the contrary, may assume important dimensions when the section is contracted. We shall see this hypothesis confirmed by the further experiments. In fact, it conforms altogether with the conclusions of the authors we have cited. As a result of his well-known experiments on the flow of air and illuminating gas in pipes, Arson developed the binomial formula:

$$h = \frac{L\delta}{D}(av + bv^2),$$


Meters
..... 5.145
..... 3.647
..... 2.862
..... 4.797
..... 4.937
..... 2.598
eters, 4.136
eters, 2.1032
eters 8.699
s. 5.640
1.364

in which the value of the coefficients a and b increases as the diameters decrease. Mr. Devillez retains the simple term and a fixed coefficient:

$$h = \frac{xL\delta v^2}{D^{1.273}},$$

but he raises the diameter, representing the function of the perimeter, to a power higher than 1, which results in giving a greater influence to the perimeter than that of the simple inverse proportion. It would be surprising if this should not be the same for underground workings.

Conclusion.—Our first three experiments gave us sufficient corroborative results to warrant our taking their average as the practical value of the coefficient of loss of head in straight gangways, with rock-walls and roof, of normal or more than normal area. This average is:

$$x = 0.00094.$$

For passages of small cross-sectional area, we have only the one observation:

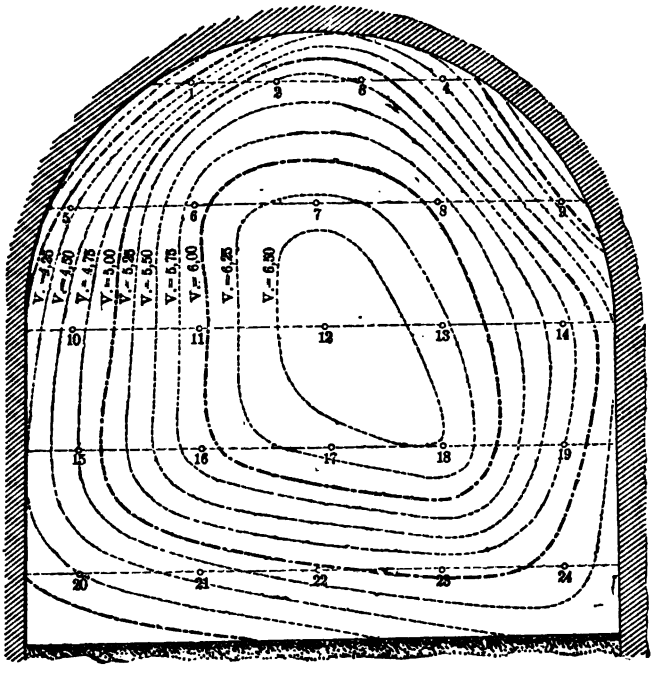
$$x = 0.00122,$$

which can be applied to gangways similar to the one on which the experiment was made. Being unable to increase the number of our experiments so as to meet every possible case, we must leave to the operator, who is called upon to use these numerical values, the care of judging of the necessary addition to, or subtraction from them, in order to allow for the curvature of the passages or the roughness of the walls.

V. GANGWAYS LINED WITH MASONRY.

Experiment No. 5.—The normal brick-lined gangway of the Bessèges mines is 2 meters wide by 2 meters high under the keystone. The section, Fig. 11, shows two vertical walls, and a full-center arch. The passage where the present experiment was made is the one above described (page 81), in which we verified the ratio of the loss of head to the square of average velocity. Its course is straight, and the sides are regular, although at one or two points it has bulged somewhat under the pressure of the ground. The surfaces are coated with a damp and slimy covering, which is common to the return-

Fig. 11.
CURVES OF EQUAL VELOCITY.



EXPERIMENT No. 5.

(November 22d, 1892.)

Brick-Lined Gangway, Normal Section.

CRÉAL MINE—SECOND LEVEL.

SCALE IN FEET AND METERS.

0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 Meters.

In. 12 9 6 3 0 1 2 Feet

VELOCITIES OBSERVED.

No.	Meters	No.	Meters	No.	Meters
1	3.980	9	3.972	17	6.338
2	5.260	10	4.589	18	6.482
3	4.205	11	5 887	19	5.251
4	4.476	12	6.669	20	4.248
5	4.102	13	6.293	21	4 621
6	5.872	14	5.307	22	4.936
7	6.310	15	4.762	23	5.126
8	5.881	16	5.890	24	4.872

Average Velocity.....meters, 5.336
Area of Gangway.....sq. meters, 3.4459
Volume Discharged.....cub. meters, 18.388

Maximum Velocity.....meters, 6.690
Ratio of Maximum to Average Velocity..... 1.254

airways of most mines. The close vicinity of the fan allowed us to maintain high air-velocities, without which the loss of head would have been scarcely perceptible:

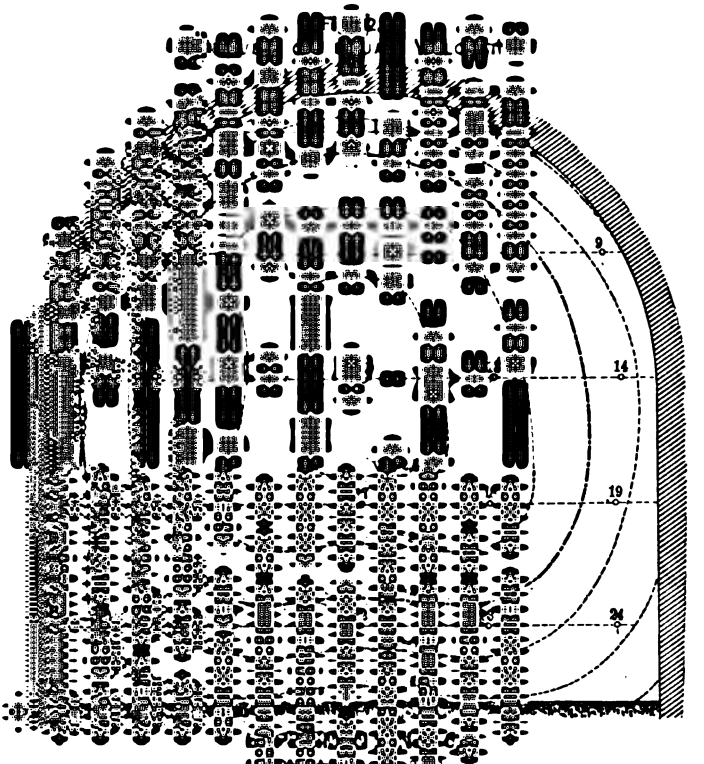
Length of course,	110.90 meters.
Average area of cross-section	3.4470 sq. meters.
Average perimeter,	7.02 meters.
Weight of one cubic meter of air,	1.184 kilogrammes.
Average velocity,	5.236 meters and 4.375 meters.
Loss of head,	1.87 mm. and 1.29 mm.
$x =$	0.00031 and 0.00030
Average value of x,	0.00030

This result is very interesting, showing, as it does, that the first effect of lining the rock-walls of underground workings with brick is to reduce to one-third the value of the loss of head. We shall see this gain still more increased when we come to compare masonwork with timber-framing and lagging. The importance of this first result led us to verify it by a further observation made in another gangway having the same characteristics and cross-section. The 7th level of the Créal mine furnished just the course to meet these requirements.

Experiment No. 6.—We could not hope to obtain any high air-velocities in this gangway, but this disadvantage was compensated by the great length of the course, which reached 330.66 meters. This course was absolutely straight and of perfectly regular profile. The air coming directly from the surface through the down-cast Brissac shaft, was not contaminated with the underground exhalations, and had left the walls presenting the same aspect and roughness as the first day they were put in. Our supply of pipes being insufficient for such a long course, we took advantage of the compressed-air pipe we found in this gangway, and from which we detached the required section (Fig. 12).

Length of course,	330.66 meters.
Average area of cross-section,	3.6080 sq. meters.
Average perimeter,	7.18 meters.
Weight of one cubic meter of air,	1.221 kilogrammes.
Average velocity,	1.963 meters and 1 950 meters.
Loss of head,	0.94 mm. and 0.93 mm.
$x =$	0.00036 and 0.00037
Average value of x,	0.00036

In this case the coefficient of loss of head presents a considerable



Meters

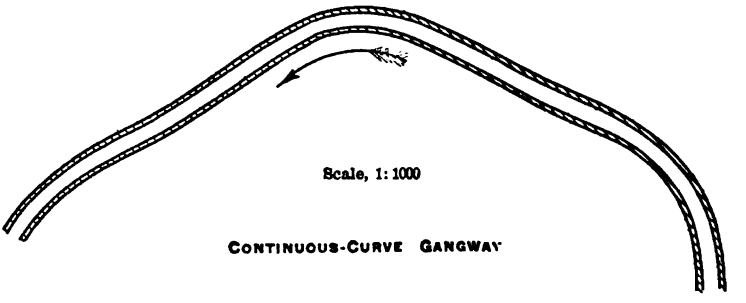
..... 2.335
..... 2.320
..... 1.843
..... 1.630
..... 1.906
..... 1.891
..... 1.910
..... 1.696

eters, 1.986
eters, 3.5078
eters, 6.967

eters, 2.500
1.259

increase, which is difficult to explain. Perhaps it may be attributable to the fact that the surfaces, which in the former experiment were damp and slimy, were dry and rough in this one. It may also be that the flanges of the compressed air-pipes caused an appreciable increase of friction. Whatever the cause, we may consider the two values obtained, 0.00030 and 0.00036, as the extreme limits of the coefficient of loss of head, in straight and normal arched gangways, and may assume their average, 0.00033, as the numerical value to be adopted in practice.

Fig. 13.

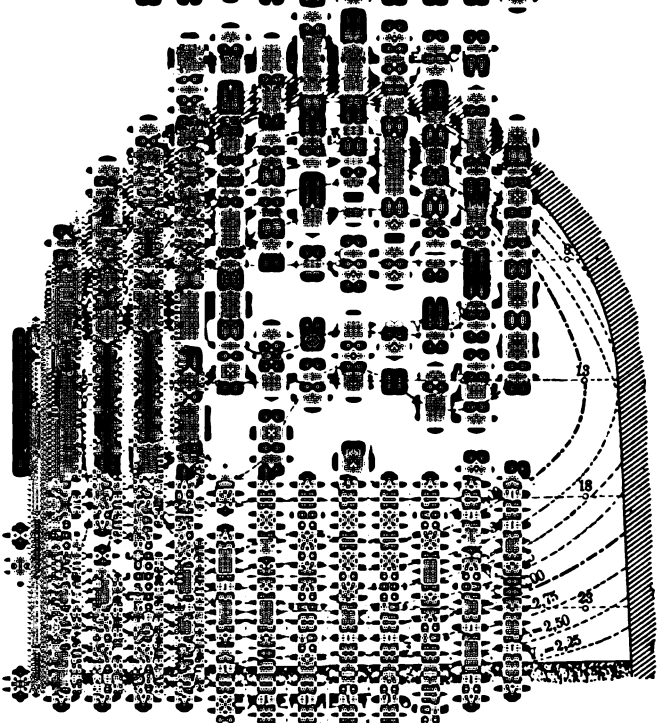


CONTINUOUS-CURVE GANGWAY

Experiment No. 7.—Unfortunately, it was not possible to devote an experiment to abnormally large arched passages. Although this type of gangway is frequently met with in the Bessèges collieries, it is found only in sections too short to give rise to any appreciable loss of head. Before passing to arched gangways of small section, we thought it would be useful to make an observation on a *normal* gangway, which described a long, continuous curve of almost a half-circle, as shown in Fig. 13. The centrifugal projection of the air-current against the concave side would give rise to increased friction and a consequently higher coefficient of loss of head, the extent of which it would be interesting to know.*

This gangway, situated on the 2d level of the Créal mine, was a continuation, with an interval of 250 meters, of the straight gangway in which experiment No. 5 was made. The cross-section is similar and fully as regular, but the velocity of the air is less and the surfaces are cleaner (Fig. 14). The straight arched gangways had given as an average value $x = 0.00033$. The comparison shows therefore

* This effect of acceleration of velocities near the concave walls is not shown very clearly on the diagram of the curves of equal velocities, of this experiment, because the area gauged was taken in the straight part which preceded the curve.



ection.

Meters
..... 4.080
..... 3.570
..... 3.325
..... 3.117
..... 3.171
..... 3.026
..... 2.629

eters, 3.793
eters, 3.0737
eters, 11.658

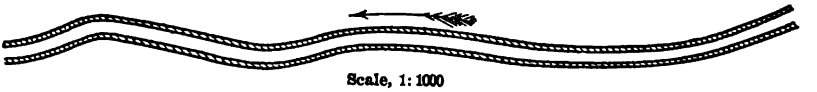
eters, 4.700
1.239

that a continuous curve in the same direction nearly doubles the coefficient of the loss of head.*

Length of course,	102.12 meters.
Average area of cross-section,	3.4560 sq. meters.
Average perimeter,	7.02 meters.
Weight of one cubic meter of air,	1.177 kilogrammes.
Average velocity,	3.404 meters and 3.075 meters.
Loss of head,	1.46 mm. and 1.18 mm.
$x =$	0.00062 and 0.00062
Average value of x,	0.00062

Experiment No. 8.—In the absence of abnormally wide arched passages, we were able to operate in two drifts of very small area, the one 1.70 meters wide, the other 1.20 meters. The first of these was driven on the 1st level of the Bessèges mine, on a very irregular seam, and consequently its course was more or less sinuous, although

Fig. 15.



Scale, 1: 1000

SINUOUS GANGWAY

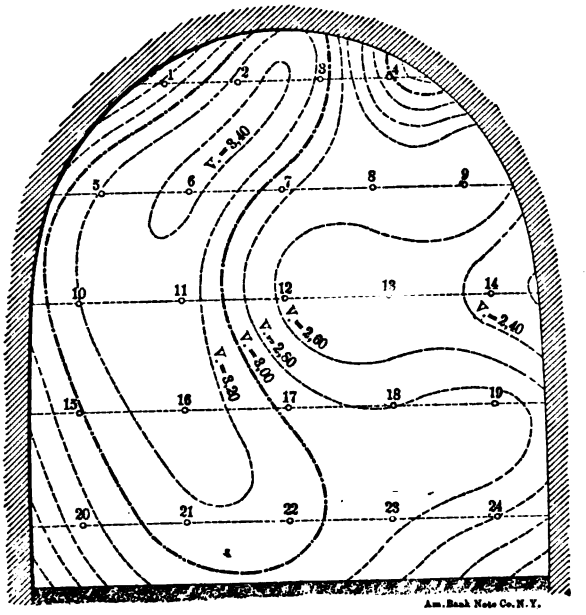
the general direction was straight (Fig. 15). The section was very regular, 1.70 meters between verticals and 1.80 meters high under the key of the arch (Fig. 16).

Length of course,	92.10 meters.
Average area of cross-section,	2.7360 sq. meters.
Average perimeter,	6.26 meters.
Weight of one cubic meter of air,	1.199 kilogrammes.
Average velocity,	2.950 meters and 3.111 meters.
Loss of head,	0.94 mm. and 1.04 mm.
$x =$	0.00051 and 0.00051
Average value of x,	0.00051

It was to be expected that the result would be intermediate be-

* The repetition, a few days later, of this experiment, which had been made at the beginning of our operations and which we had at first thought incorrect, contributed to inspire us with increased faith in our methods of observation. On the first occasion, our pipe-line had been inadvertently extended about a dozen meters beyond the arched portion and into the plain rock part of the drift, and we found for the value of the coefficient $x = 0.00055$. The second time the pipe was confined to the arched portion, and the value of x was lowered to 0.00062.

Fig. 16.
CURVES OF EQUAL VELOCITY



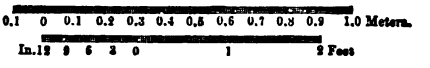
EXPERIMENT No. 8.

(November 15th, 1892.)

Brick-Lined Gangway, Intermediate Section.

CRÉAL MINE—FIRST LEVEL.

SCALE IN FEET AND METERS.



VELOCITIES OBSERVED

No.	Meters	No.	Meters	No.	Meters
1	2.645	9	2.771	17	2.950
2	3.299	10	3.186	18	2.797
3	3.108	11	3.300	19	2.838
4	2.569	12	2.455	20	2.720
5	3.216	13	2.505	21	3.118
6	3.415	14	2.331	22	3.096
7	2.848	15	2.985	23	2.833
8	2 704	16	3.281	24	2.608

Average Velocity	meters,	2.878
Area of Gangway	sq. meters,	2.7693
Volume Discharged	cub. meters,	7.970
Maximum Velocity	meters,	3.420
Ratio of Maximum to Average Velocity		1.188

tween those for the straight and the continuously curved gangways, and this expectation was fairly verified. Still, the result was not exactly the mean of the other two, but much nearer the higher one, which leads us to infer that the contraction of area begins to exert the same sort of influence that we spoke of in experiment No. 4, and which we might designate as the *law of the small sections*. As we shall presently see, the next experiment confirms this hypothesis.

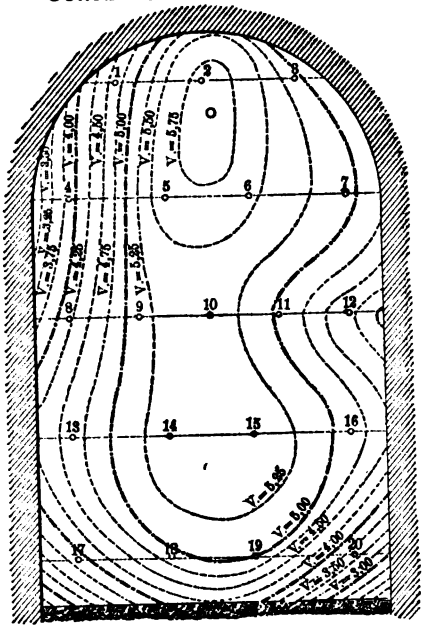
Experiment No. 9.—The second small-section arched gangway was also situated on the 1st level of Bessèges. It measured only 1.20 meters wide by 1.90 meters high. It was used as a passage for the Créal mines, and like the preceding course, its general direction was straight, but it had some few bends. We were easily able to maintain air-velocities of 4 to 5 meters a second, which compensated for the small length, this being the shortest course used in any of our experiments (Fig. 17).

Length of course,	61.30 meters.
Average area of cross-section,	2.1250 sq. meters.
Average perimeter,	5.67 meters.
Weight of one cubic meter of air,	1.199 kilogrammes.
Average velocity,	4.535 meters and 4.569 meters.
Loss of head,	1.82 mm. and 1.88 mm.
$x =$	0.00054 and 0.00055
Average value of x,	0.00055

Apart from the length, this gangway compares exactly with the preceding one. It has the same bends, the same profile, and the same character of walls. Therefore, it would be difficult to explain the considerable increase of the coefficient of loss of head, in passing from one to the other, if we were not to admit the *law of the small sections* of which we spoke above, and according to which this coefficient would increase as the section decreases. At all events, we may consider that the results just obtained lend considerable support to this law.

Conclusion.—The somewhat divergent values furnished by experiments 5 and 6 for the coefficient of the loss of head in normal and straight-arched gangways lead us to adopt their average 0.00033 for practical use in mining calculations. If the normal-arched gangway deviates from a straight line for a continuous curve in one direction, the coefficient of loss of head may rise to 0.00062. If the course is simply sinuous, the rise would stop at 0.00051, yet it may reach 0.00055 with passages of subnormal cross-sectional area. Such are

Fig. 17.
CURVES OF EQUAL VELOCITY



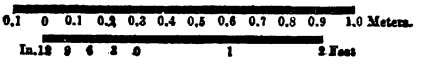
EXPERIMENT No. 9.

(November 13th, 1892.)

Brick-Lined Gangway, Small Section.

CRÉAL MINE—FIRST LEVEL.

SCALE IN FEET AND METERS.



VELOCITIES OBSERVED.

No.	Meters	No.	Meters	No.	Meters
1	4.604	8	4.201	15	5.43[illegible]
2	5.812	9	5.176	16	4.869
3	5.075	10	5.368	17	3.852
4	3.807	11	4.947	18	4.875
5	5.633	12	4.275	19	4.971
6	5.542	13	4.465	20	3.655
7	5.053	14	5.357		

Average Velocity	meters,	4.875
Area of Gangway	sq. meters,	2.0086
Volume Discharged	cub. meters,	9.792
Maximum Velocity	meters,	5.860
Ratio of Maximum to Average Velocity		1.202

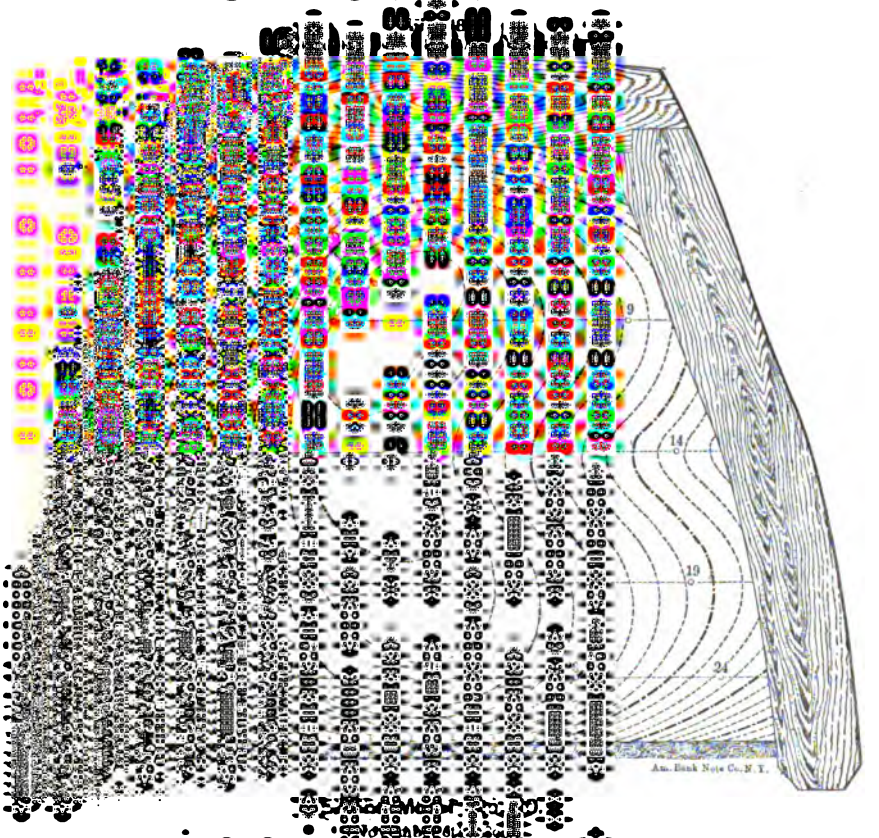
the results with brick-lined passages. We had hoped to obtain a more complete and regular scale, but it is difficult to find in underground works perfect regularity or similarity in any two passages, especially when, in addition, they would meet all the requirements and exigencies of our method of observation. With the best of intentions, it was impossible for us to do better.

VI. Timbered Gangways.

Experiment No. 10.—The timber-sets used in the Bessèges collieries are composed of a cap and two legs, the latter spreading somewhat at the foot, care being taken that where the legs are not straight the concave side is always placed inwards. Their spacing varies from 1.20 to 1.30 meters from center to center. The spaces between sets are lagged up with small poles. The average section of a timbered gangway should be an average between a section taken inside the set and one taken between sets; but this would lead to complicated calculations, and not to very clear results. It seemed preferable to us to measure the sectional areas and perimeters inside of the sets, and to regard the excess of width between them as simple irregularities of surface.*

The gangway where experiment No. 10 was carried on was the regular main haulage or normal gangway, timbered with oak sets, and having an average height of 1.85 meters under the cap, a width of 1.20 meters at the upper part of the frame, and 2.10 meters at the foot. Conveniently situated at the entrance to the second level of the Créal mine and near the fan, we had been already able to prove here, under the best conditions, the law of the relation of the loss of head to the square of the average velocity, as previously described. As we then remarked, this gangway, being pretty old and having been repaired frequently, showed considerable irregularity of profile. The old and new sets follow one another very closely, but with considerable variations of height and shape, the only rule being to leave sufficient room for the passage of the horses and the trains. The course is straight, except for the inevitable undulations which occur in all gangways driven on the floor of a bed (Fig. 18).

* To be quite accurate, we should add to the sectional areas measured all the spaces between the laggings and the sides and roof, but as the velocity of the air in these spaces is necessarily very low, it seemed unwise to complicate our calculations needlessly. During the time of gauging the air we always stopped up these spaces with hay, so as to make sure of measuring the entire supply.



ction.

	Meters
	4.923
	4.314
	3.204
	1.937
	4.070
	4.684
	4.033
	2.425

eters, 3.781
eters, 3.4894
eters, 13.194

eters, 5.470
1.447

Length of course,	97.08 meters.
Average area of cross-section,	3.0370 sq. meters.
Average perimeter,	6.91 meters.
Weight of one cubic meter of air,	1.201 kilogrammes.
Average velocity,	4.202 meters and 3.655 meters.
Loss of head,	6.53 mm. and 4.96 mm.
$x =$	0.00168 and 0.00168
Average value of x,	0.00168

As was to be expected, the coefficient of loss of head assumes here a very high value, much above anything we had heretofore observed. In order to thoroughly prove the accuracy of this important result, it became necessary to corroborate it by a duplicate observation, made under similar conditions.

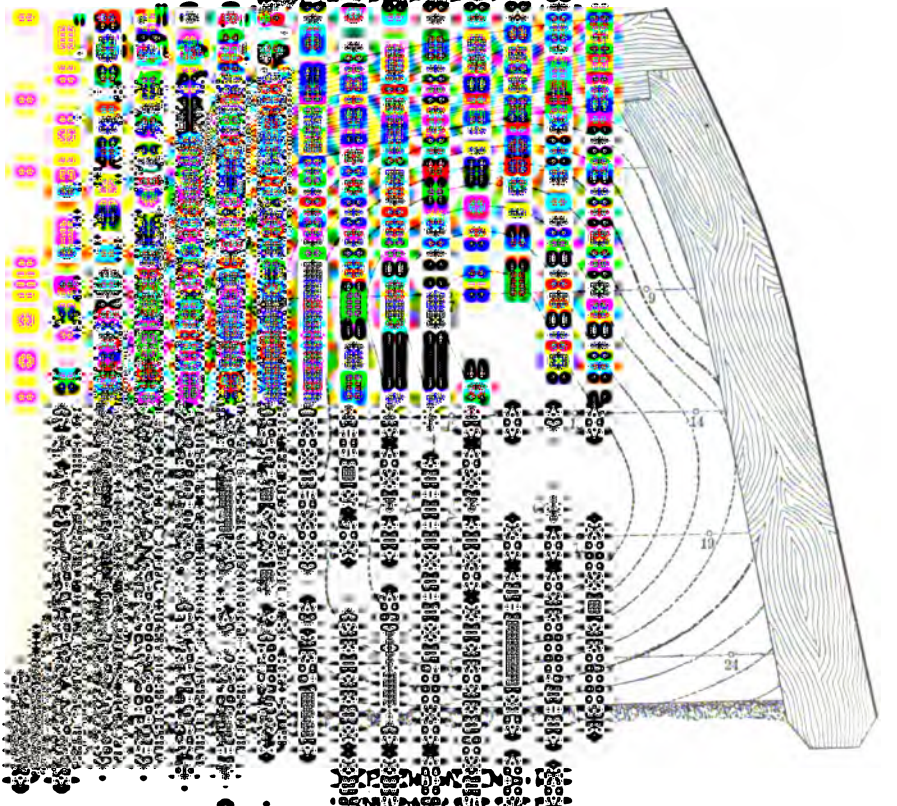
Experiment No. 11.—The newly repaired "St. Felix" entry on the first level of the Créal mine presented an excellent example of a normal gangway, correctly and accurately timbered. By a rare chance this gangway was entirely separated, throughout its length, from the other workings. The average height under the caps was 1.95 meters, the width at the top was 1.20 and at the foot of the legs 2.20 meters. The sets were of pine and spaced on an average at 1.20 meter-centers. In certain portions, and notably at the points where the air-gauging occurred, the caps were inclined quite perceptibly, following the slant of the roof of seam (Fig. 19).

As in the previous case, the course was straight, with very slight deviations. With some difficulty we were able to maintain an average velocity of 2.15 meters per second, which, although too low for observation in an arched gangway, gave, in this case, an appreciable loss of head.

Length of course,	80.25 meters.
Average area of cross-section,	3.337 sq. meters.
Average perimeter,	7.23 meters.
Weight of one cubic meter of air,	1.169 kilogrammes.
Average velocity,	2.151 meters and 2.146 meters.
Loss of head,	1.13 mm. and 1.12 mm.
$x =$	0.00144 and 0.00143
Average value of x,	0.00144

In this case the reduction of the coefficient of loss of head is due to the greater regularity of the section of the gangway under observation.

Experiment No. 12.—Large timbered drifts are very seldom met with in the Bessèges mines, and even then, only on short lengths at



Meters

..... 2.757
..... 2.903
..... 2.211
..... 1.430
..... 2 011
..... 2.285
..... 2.114
..... 1.721

meters, 2.147
meters, 3.2480
meters, 6.973

meters. 2.950
1.374

the stations and turnouts; we, therefore, had to give up testing them, with less regret, however, than in the case of similar arched gangways, which would have furnished a step in advance toward railroad-tunnels and sewers. The small-section gangways, whether timbered or untimbered, are of very frequent occurrence, constituting as they do the whole network for the characteristic haulage-system of our workings. Unfortunately, these entries are seldom isolated from the neighboring rooms. They run along the gob-piles, cross other traffic-entries, branch out from or run into one another in such a way that it required a long search to find a section absolutely isolated and regularly timbered, which would be long enough to permit our observations.

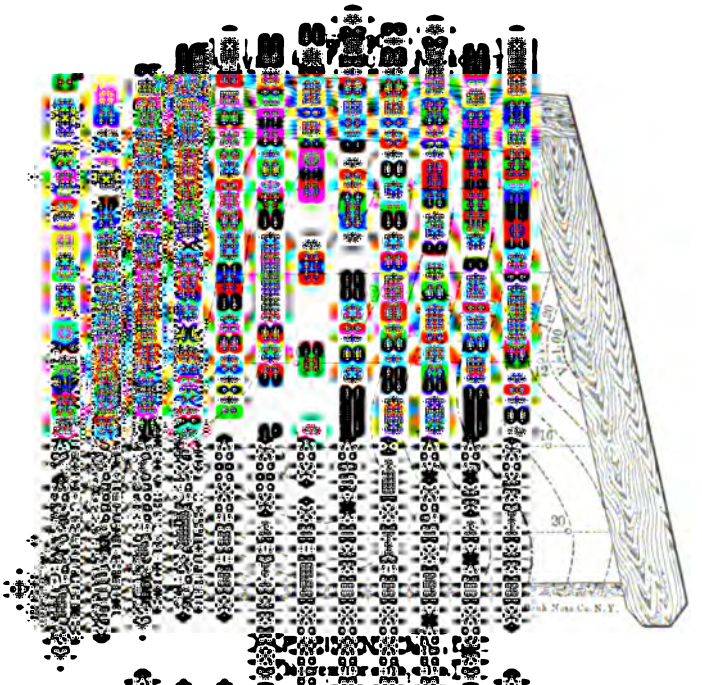
This section lying between the third and fourth level of the Créal mine is part of the independent return-airway of the seventh level, which has been subject several times to sudden outbursts of fire-damp. It rises into the Ste. Barbe bed with an average grade of 0.3 meter to the meter. The sets average 1.50 meters high under the cap; 1.10 meters wide at the top, and 1.70 meters at the foot of the legs, with an average spacing of 1.20 meters (Fig. 20).

The course is generally straight, with only slight vertical and horizontal undulations.

Length of course,	92.53 meters.
Average area of cross-section,	2.0350 sq. meters.
Average perimeter,	5.77 meters.
Weight of one cubic meter of air,	1.200 kilogrammes.
Average velocity,	2.310 meters and 2.138 meters.
Loss of head,	3.32 mm. and 2.71 mm.
$x =$	0.00243 mm. and 0.00233
Average value of x,	0.00238

The coefficient of the loss of head shows an increase that is hard to explain. Doubtless the undulations were greater than with the previous experiments, and the surface irregularities, due to the spaces between the sets, were relatively of greater importance; nevertheless it would be impossible to explain such an increase except for the influence of the reduced sections of which we have spoken so often. From the results which we obtained, it would appear that this influence is particularly potent in timbered gangways.

Conclusion.—The two values for the coefficient of loss of head determined in straight and normal timbered passages, represent the two extremes of actual practice, viz.: for new workings, and for old



Meters.

Meters
..... 2.240
..... 1.710
..... 2.192
..... 2.746
..... 2.438
..... 1.795

meters, 2.383
meters, 2.0039
meters, 4.775

meters, 3.020
1.267

and frequently repaired gangways. For general use we may safely use their average, viz.:

$$x = 0.00156$$

This value increases rapidly as the cross-sectional area decreases, and, in the single case of small-section passages that we observed, it reached 0.00238. We may add that this gangway was slightly sinuous.

VII.—General Conclusions.

Recapitulated Table.—In order to facilitate a comparison of the results of our twelve observations, we have assembled them in the following table:

		Averages.
Rock gangways.	No. 1.—Straight, normal section, $x = 0.00092$	
	No. 2.—Straight, normal section, $x = 0.00086$	0.00094
	No. 3.—Straight, large section, $x = 0.00104$	
	No. 4.—Straight, normal section, $x =$ . . .	0.00122
Brick-lined arched gangways.	No. 5.—Straight, normal section, $x = 0.00030$	
	No. 6.—Straight, normal section, $x = 0.00036$	0.00033
	No. 7.—Continuous curve, normal section, $x =$	0.00062
	No. 8.—Sinuous, intermediate section, $x =$	0.00051
	No. 9.—Sinuous, small section, $x =$	0.00055
Timbered gangways.	No. 10.—Straight, normal section, $x = 0.00168$	
	No. 11.—Straight, normal section, $x = 0.00144$	0.00156
	No. 12.—Slightly sinuous, small section, $x =$	0.00238

This table shows that notwithstanding individual variations, each group is confined within pretty close lines, while the differences between groups are much greater. Our three types of gangways are clearly characterized by the amount of head which they absorb, and as might have been expected, they rank in the following order:

First.—Brick-lined arched gangways, x varies from 0.00030 to 0.00062
Second.—Unlined rock-gangways, . x varies from 0.00086 to 0.00122
Third.—Timbered gangways, . . x varies from 0.00144 to 0.00238

But in addition a careful examination of our tables, however incomplete they may be, points out some instructive data, to which we have already drawn attention. We shall briefly recall them here, while examining each in turn with respect to the influence of bends in the air-ways, the section and the character of the walls.

Influence of Deflections from the Straight Line.—The group of

arched gangways is the only one that is sufficiently complete to furnish an idea of the influence of bends in the course on the indicated loss of head. Without leaving the normal gangway we find this interesting progression:

First.—Arched gangway, straight, ...	$x = 0.00033$
Second.—Arched gangway, only sinuous, . . .	$x = 0.00051$
Third.—Arched gangway, continuous curve, . . .	$x = 0.00062$

which shows that the loss of head is nearly doubled by considerable curvature of the passages.

Influence of the Section.—The large sections were only once experimented on, viz., in No. 3. The value of the coefficient differed very slightly from those given for normal sections, and therefore we have included it in figuring the average coefficient for general practice. The small sections were observed once on each type of gangway, and each time they gave rise to a very perceptible increase in the coefficient for the loss of head. Especially is this the case for timbered gangways, as may be judged by the following comparative table:

	Normal section.	Small section.
Arched gangways, ...	$x = 0.00033$	$x = 0.00055$
Unlined rock gangways, . . .	$x = 0.00094$	$x = 0.00122$
Timbered gangways, ...	$x = 0.00156$	$x = 0.00238$

We must not forget, however, that these narrow passages were more irregular and sinuous than the normal gangways, to which they are compared, but at the same time, the increase appears too large and too regular not to make it necessary to introduce a new influence, which we have spoken of as the *law of the small sections.* As we have previously observed, several authorities have been forced to admit that the loss of head in air- and gas-pipes increased in proportion as the diameter decreased. Why should this not also apply to mine gangways? We therefore think it best to accept this law provisionally in the vague terms in which we have presented it here, until such time as its numerical value shall have been established by more numerous and accurate experiments.

The average value for the coefficient of the loss of head proposed by Mr. Devillez for the entirety of mine-workings ($x = 0.00180$) seems to thoroughly confirm this law. If we look to the numerical scale of our general table for this value, we find that it was only once exceeded in the case of small-section, timbered gangways. It would therefore be too high for an average of gangways similar to

those on which we made our observations.* But the conditions under which Mr. Devillez and his colleagues operated, covered only small sections. The average of their sections hardly exceeded two square meters, and were often reduced to one square meter. Under these conditions, the law above quoted, together with the amount of resistance opposed by the periphery of the closed passages in circuit, explains very clearly the high readings observed by the eminent professor. As a result of this law, we find that mine-operators have special interest in increasing the dimensions of their air-ways, because by so doing they diminish the loss of head, first by lessening the velocity of the air-current, and secondly by a corresponding lowering of the coefficient x.

Influence of the Walls.—In order to define exactly the influence of the character of the walls, it will be only necessary to confine ourselves to the normal, straight gangways, which in every other respect are capable of comparison, and which were all subjected to duplicate observations, in different parts of the mine. In this way we obtain the following series, which is thoroughly characteristic.

1st. Brick-lined arched gangways, ...	$x = 0.00033$
2d. Unlined rock-gangways, ...	$x = 0.00094$
3d. Timbered gangways, ...	$x = 0.00156$

By a comparison of these figures we obtain information of the highest importance, which may be expressed as follows: In the choice of lining for air-ways, considerations of strength and first cost should not alone be considered; close attention should likewise be given to the influence which this lining will have on the intensity of the air-current that is to be circulated through it.

We shall apply this statement to a practical example of every-day mining: It becomes rarer day by day to be able to exploit mineral-deposits by short entries only, either vertical or horizontal. Very often the difficulties of a mountainous country, the presence of quicksands, or simply the wish to utilize old shafts already sunk and fairly well situated and equipped for distant workings, necessitate driving long gangways, through which the air-currents must circulate, either from the surface to the workings, or *vice versâ*. We could cite any number of such cases, but without this being neces-

* The value of the coefficient x actually resulting from Mr. Devillez's experiments was in reality 0.001624; but to account for the natural action which occurred during the observations, but which escaped the gauge, Mr. Devillez thought it necessary to increase the figure obtained to 0.00180.

sary, it will be admitted that we shall be well within the limit of reason, in supposing a case where the air would have to pass through a normal, straight gangway 400 meters long and 3.60 square meters in cross-sectional area. We will assume the discharge equals 18 cubic meters per second, thus giving an average velocity of 5 meters. Under these conditions, we find that the amount of head consumed by this passage will be as follows:

	mm.
If brick-lined and arched,	6.6
If an ordinary rock-cut,	19.5
If timbered,	32.6

Therefore, if the mine-workings themselves require a pressure of 20 mm. of water, the vacuum which the exhaust-fan will have to produce to furnish this will be:

	mm.
In the first case,	26.6
In the second case,	39.5
In the third case,	52.6

Thus the required duty of the fan is doubled if the 400-meter gangway is timbered instead of being brick-lined.*

The matter which we are considering is important enough to be studied in all its phases. For example, what would be the variation of discharge, with each of the three linings, if we suppose that the fan, regulated to a practical speed, maintains a vacuum of 40 mm. of water in the workings? The head absorbed by the working-chambers of a mine cannot be computed *a priori*, because the openings, cross-passages, irregular shaped gob-piles, and daily changes in the size and shape of the chambers present much too complicated a network for accurate analysis. In order to overcome this difficulty, I proposed as far back as 1872 the *a posteriori* method of *equivalent orifice*, which has had the good fortune to meet with a very favorable reception at the hands of mine-operators. This method consists in substituting for the mine to be considered, the equivalent thin-lipped orifice, requiring the same height of head for the discharge of an equal volume of air. The area of this orifice *a*

* The section of 3.60 square meters, which we have adopted in our calculations, represents fairly well the mean section of the normal haulage-gangway, whether brick-lined or unlined. It might be a little large for the normal timbered gangway. We have adopted the following values for the perimeters: lined gangway 7.17 m.; unlined, 7.45 m.; timbered, 7.52 m. The weight of one cubic meter of air is taken as 1.2 kilogrammes, as in all our calculations.

is obtained when the head h and the discharge V are known, by means of the formula:*

$$a = \frac{0.38\,V}{\sqrt{h}}.$$

Supposing that, in the case under consideration, the mine workings, outside of the intake- or discharge-passage of 400 meters, are equal to an orifice of 1.5 square meters, the required head obtained by the foregoing formula is:

$$h = \frac{(0.38)^2 V^2}{a^2} = 0.0642\,V^2.$$

On the other hand, the 400 meters of the assumed passage will absorb a head equal to:

$$h = x\,\frac{400 p v^2 \delta}{s \delta_0},$$

which formula, by substituting for the average velocity, v, the quotient, $\frac{V}{s}$, of the discharge by the area, and admitting $\delta = \delta_0$, becomes

$$h = x\,\frac{400p}{s^3}\,V^2.$$

These two heads together give a total to the vacuum produced by the fan, or 40 mm.:

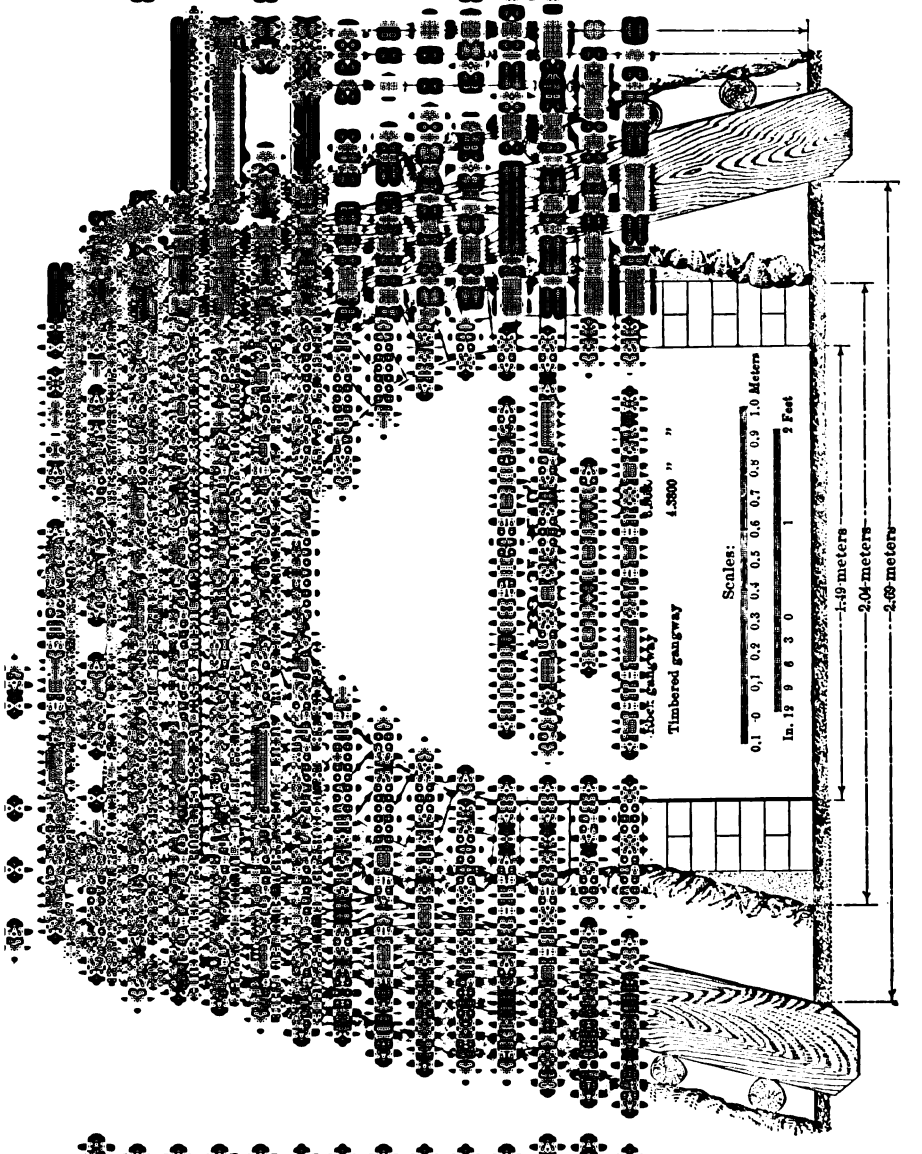
$$0.0642\,V^2 + x\,\frac{400p}{s^3}\,V^2 = 40,$$

therefore, the discharge is:

$$V^2 = \frac{40}{0.0642 + x\frac{400p}{s^3}}.$$

We know that $s = 3.60$ square meters; we also know the value of the perimeter, p (see note p. 109). It remains only to give to the coefficient x of loss of head, the values corresponding to the three kinds of lining to be able to calculate under the three hypotheses the volume V of air discharged per second. We find thus that, according to the character of the lining used, the discharge will be equal to:

* This formula is deduced from that of the discharge through thin-lipped orifices $V = Ka\sqrt{2g\frac{h}{\delta}}$ by assuming the coefficient of contraction K = 0.65 and the weight of the cubic meter of air = 1.2 kilogrammes.



clearly enough the influence of timber-
ne air-ways.

Possibly, this advantage would be still more apparent, if the brick walls and arches were plastered over with smooth cement, and possibly, even, the resulting gain would warrant the extra outlay. We regret not having been able to determine this fact. In Fig 21 is shown a very striking graphical illustration of the above results. Taking as basis the cross-section of the rock-passage of our experiment, No. 2, we have superimposed the contours of an arched and a timbered gangway, which, for an equal discharge, would absorb the same head. These outlines surround one another, increasing from the brick-lined section to the timbered one, so as to compensate, by loss of velocity, for the increase in the coefficient for the loss of head. As shown, the contour of the arched gangway leaves a space nearly all around inside the contour of the rock-cut, sufficient in width to introduce a brick-lining of 0.22 meter, showing that it is possible to line any normal rock gangway with brick, 0.22 meter thick, without in any way impairing its efficiency as an air-way. The inside contour of the timbered section is much larger than that of the rock-gangway, and, as it is necessary to drive the passage large enough to insert the timbers, it proves that if timbering is determined upon, it will be requisite to double the size of the drift if we wish to maintain the same standard loss of head.

In closing this paper, we must acknowledge that our experiments have only confirmed what might have been expected. We think, however, that it is not useless to replace theories by numerical certainties. Whatever may be said, it is evidently to the interest of mine-operators, as well as their duty, when working fiery mines, to increase as much as possible the intensity of the air-currents in their workings, and this will be sooner and better attained by endeavoring to diminish, throughout, the loss of head, rather than by hunting up more efficient ventilating machines. Beside the old and effective method of enlarging the cross-section so as to lessen the velocities, our experiments show that there are others which should not be neglected, viz., the substitution of masonry for timber-work, and even for rock-cuttings; the straightening of crooked lines, and the elimination of subnormal cross-sections, which not only seriously affect the acceleration of the air-velocities, but also sensibly increase the coefficient of the loss of head. We hope the results of our work will prove really useful. This has been our sole idea in undertaking the study, and we trust we may not be disappointed.

FURTHER OBSERVATIONS ON THE RELATIONS BETWEEN THE CHEMICAL CONSTITUTION AND PHYSICAL CHARACTER OF STEEL.

BY WILLIAM R. WEBSTER, PHILADELPHIA, PA.

(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

I HAVE continued the investigation of the Pottstown Iron Company's basic Bessemer steel plates on the line referred to in my paper of last October (*Trans.*, xxi., 766), and have added a study of the hardening effects of sulphur, which were not taken into account at that time. The results are so encouraging that I now give them in full. For some months we have graded all the steel at these works by the table given in my former paper, and checked the grading by the forging-tests as described in the paper of Mr. Joseph Hartshorne, read at the same meeting (*Trans.*, xxi., 743). The steel thus graded was bloomed for the plate orders. Then one slab was rolled into a plate for the order, and a tension-test was made of this plate. By the result of this tension-test we were guided in rolling the balance of the heat. Out of several hundred heats graded in this manner, 95 per cent. met the requirements of the orders in every respect, and were accepted; but these results will no doubt be improved upon, when the influence of sulphur is also considered.

The hardening effect of sulphur seems to be about 500 pounds per each .01 per cent. of increase. In the table accompanying the present paper, the ultimate strength with .065 per cent. sulphur agrees with the old table where sulphur was not considered; that is, for all steels with less than .065 per cent. sulphur we now get lower results, and for those with more sulphur, higher results. Making this allowance for sulphur, the assumed ultimate strength of a $\frac{8}{8}$-inch plate of pure iron is reduced from 38,000 pounds per square inch to 34,750 pounds. With this as a basis, I have constructed my new table, giving each of the elements, carbon, phosphorus and manganese the same hardening effect as before, to wit:

Carbon is credited with a constant effect of 800 pounds per each 0.01 per cent.

Phosphorus shows greater effect in high-carbon than in low-carbon steels. For 0.07 and 0.08 C, it has about the same effect as carbon, that is, 800 pounds for each .01 P. This increases to 1500 pounds per .01 P in 0.15 C steel, or nearly twice the effect of carbon. This

increase in the effect of phosphorus as carbon increases is gradual, proceeding about as follows:

For Carbon. Hundredths Per cent.	Increase of Ultimate Strength per 0.01 Per cent. P Added. Lbs.	Effect of Unit of P to Unit of C. As 1 to
9	900	1⅛
10	1000	1¼
11	1100	1⅜
12	1200	1½
13	1300	1⅝
14	1400	1¾
15	1500	1⅞
16	1500	1⅞
17	1500	1⅞

The effect per unit of manganese seems to decrease as the percentage of this element increases. For instance, steels of 0.20 and 0.30 Mn show greater difference in ultimate strength than steels of 0.50 to 0.60 Mn, all other elements being the same. I have endeavored to cover this point irrespective of the percentage of carbon or phosphorus, but upon further investigation it may be necessary to take one or both of these elements into account in estimating the effect of high and low manganese.

Assuming the first addition of 0.15 per cent. manganese to increase the ultimate strength 3600 pounds, we have:

Increase in Ultimate Strength by Successive Increments of Manganese.

Manganese, Per cent.		Increase in Ultimate Strength.	Total Increase in Ultimate Strength from 0. Manganese.
From	To	Lbs. per square inch.	Lbs. per square inch.
0.00	0.15	3600	3,600
0.15	0.20	1200	4,800
0.20	0.25	1100	5,900
0.25	0.30	1000	6,900
0.30	0.35	900	7,800
0.35	0.40	800	8,600
0.40	0.45	700	9,300
0.45	0.50	600	9,900
0.50	0.55	500	10,400
0.55	0.60	500	10,900
0.60	0.65	500	11,400

Silicon is so very low in this steel (there being only a trace) that its hardening effect has not been considered at all, but with other steels it should be considered.

The tabulated tests were made in the ordinary manner in the course of filling orders, and the analyses were made of drillings taken from the broken test-pieces near the point of fracture. In

this way many chances of error were eliminated. The results of each test are given together with the percentage of carbon, sulphur, phosphorus and manganese. The ultimate strength, as estimated by the table, is compared with the actual ultimate strength, and the difference given with its proper sign in the right hand column. The tests of the sheared plates are given in one group and those of the universal mill plates in another; this is done to keep the conditions as nearly the same as possible and to show more clearly the effect of the chemical composition of the steel. An inspection of the tables will show the general principle followed in the investigation, and the efforts made to bring out clearly the hardening effect of each element. In a separate set of tables I have given the number of the tests in which the estimated ultimate strength comes within plus or minus 1000 pounds of the actual result obtained on the testing machine; and with this are also tabulated the tests coming within 1000 to 2000 pounds, and so on to those of over 5000 pounds. Each group is given its appropriate sign.

The results are also arranged according to the thickness of plates and their ultimate strength as follows: Under 54,000 pounds—54,000 to 62,000 pounds—62,000 to 70,000 pounds—over 70,000 pounds—in order to show the effect the thickness of material has on its ultimate strength and the allowance that should be made. On this point my results are not very satisfactory, but during the investigation the importance of controlling the temperature at which the plates are finished was brought out very forcibly.

In basic open-hearth steel, we have deducted 2100 pounds from the estimated ultimate strength; this has given fair results, but the amount of deduction may have to be modified in using the new table.

From the results obtained, I believe that I am safe in saying that in all rolled steel the quality depends on the size of the bloom, or ingot, from which it is rolled, the work put on it, the temperature at which it is finished, and the chemical composition of the steel; that is, a table of this kind could be used for beams, angles, bars, etc. For instance, a 6 x 6 x $\frac{5}{8}$-inch angle with a given chemical composition might give 4000 pounds higher ultimate strength than indicated by my table; but by making this allowance, the table could be used to advantage to show what ultimate strength another heat of steel with different chemical composition would give if rolled into the same sized angle. I trust that this point is clear and that some of the shape-mills will take the matter up and let us hear from them.

TABLE I.—*Estimated Ultimate Strengths.*

For Carbon, .06 to .25; Phosphorus, .00 to .10; Manganese and Sulphur, .00 in all cases.

Carbon =	.06	.07	.08	.09	.10	.11	.12	.13	.14	.15	.16	.17	.18	.19	.20	.21	.22	.23	.24	.25
Phos. .000	39,550	40,350	41,150	41,950	42,750	43,550	44,350	45,150	45,950	46,750	47,550	48,350	49,150	49,950	50,750	51,550	52,350	53,150	53,950	54,750
" .005	39,950	40,750	41,550	42,400	43,250	44,100	44,950	45,800	46,650	47,500	48,300	49,100	49,900	50,700	51,500	52,300	53,100	53,900	54,700	55,500
" .01	40,350	41,150	41,950	42,850	43,750	44,650	45,550	46,450	47,350	48,250	49,050	49,850	50,650	51,450	52,250	53,050	53,850	54,650	55,450	56,250
" .015	40,750	41,550	42,350	43,800	44,250	45,200	46,150	47,100	48,050	49,000	49,800	50,600	51,400	52,200	53,000	53,800	54,600	55,400	56,200	57,000
" .02	41,150	41,950	42,750	43,750	44,750	45,750	46,750	47,750	48,750	49,750	50,550	51,350	52,150	52,950	53,750	54,550	55,350	56,150	56,950	57,750
" .025	41,550	42,350	43,150	44,200	45,250	46,300	47,350	48,400	49,450	50,500	51,300	52,100	52,900	53,700	54,500	55,300	56,100	56,900	57,700	58,500
" .03	41,950	42,750	43,550	44,650	45,750	46,850	47,950	49,050	50,150	51,250	52,050	52,850	53,650	54,450	55,250	56,050	56,850	57,650	58,450	59,250
" .035	42,350	43,150	43,950	45,100	46,250	47,400	48,550	49,700	50,850	52,000	52,800	53,600	54,400	55,200	56,000	56,800	57,600	58,400	59,200	60,000
" .04	42,750	43,550	44,350	45,550	46,750	47,950	49,150	50,350	51,550	52,750	53,550	54,350	55,150	55,950	56,750	57,550	58,350	59,150	59,950	60,750
" .045	43,150	43,950	44,750	46,000	47,250	48,500	49,750	51,000	52,250	53,500	54,300	55,100	55,900	56,700	57,500	58,300	59,100	59,900	60,700	61,500
" .05	43,550	44,350	45,150	46,450	47,750	49,050	50,350	51,650	52,950	54,250	55,050	55,850	56,650	57,450	58,250	59,050	59,850	60,650	61,450	62,250
" .055	43,950	44,750	45,550	46,900	48,250	49,600	50,950	52,300	53,650	55,000	55,800	56,600	57,400	58,200	59,000	59,800	60,600	61,400	62,200	63,000
" .06	44,350	45,150	45,950	47,350	48,750	50,150	51,550	52,950	54,350	55,750	56,550	57,350	58,150	58,950	59,750	60,550	61,350	62,150	62,950	63,750
" .065	44,750	45,550	46,350	47,800	49,250	50,700	52,150	53,600	55,050	56,500	57,300	58,100	58,900	59,700	60,500	61,300	62,100	62,900	63,700	64,500
" .07	45,150	45,950	46,750	48,250	49,750	51,250	52,750	54,250	55,750	57,250	58,050	58,850	59,650	60,450	61,250	62,050	62,850	63,650	64,450	65,250
" .075	45,550	46,350	47,150	48,700	50,250	51,800	53,350	54,900	56,450	58,000	58,800	59,600	60,400	61,200	62,000	62,800	63,600	64,400	65,200	66,000
" .08	45,950	46,750	47,550	49,150	50,750	52,350	53,950	55,550	57,150	58,750	59,550	60,350	61,150	61,950	62,750	63,550	64,350	65,150	65,950	66,750
" .085	46,350	47,150	47,950	49,600	51,250	52,900	54,550	56,200	57,850	59,500	60,300	61,100	61,900	62,700	63,500	64,300	65,100	65,900	66,700	67,500
" .09	46,750	47,550	48,350	50,050	51,750	53,450	55,150	56,850	58,550	60,250	61,050	61,850	62,650	63,450	64,250	65,050	65,850	66,650	67,450	68,250
" .095	47,150	47,950	48,750	50,500	52,250	54,000	55,750	57,500	59,250	61,000	61,800	62,600	63,400	64,200	65,000	65,800	66,600	67,400	68,200	69,000
" .10	47,550	48,350	49,150	50,950	52,750	54,550	56,350	58,150	59,950	61,750	62,550	63,350	64,150	64,950	65,750	66,550	67,350	68,150	68,950	69,750
.001 Phos.—	80 lbs.	80 lbs.	80 lbs.	90 lbs.	100 lbs.	110 lbs.	120 lbs.	130 lbs.	140 lbs.	150 lbs.	150 lbs.	150 lbs.	150 lbs.	150 lbs.	150 lbs.	150 lbs.	150 lbs.	150 lbs.	150 lbs.	150 lbs.

TABLE I.—(continued). *Additions for Sulphur.*

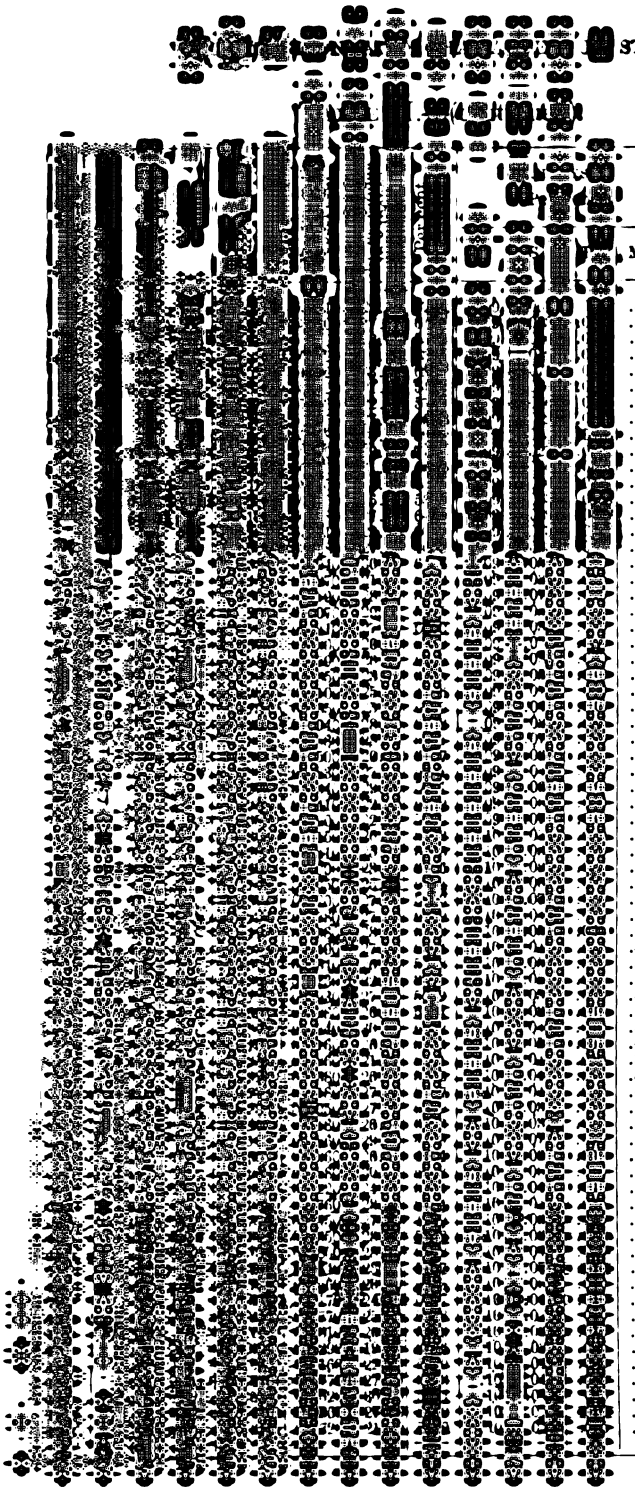
	.0	.001	.002	.003	.004	.005	.006	.007	.008	.009
0	000	50	100	150	200	250	300	350	400	450
.01	500	550	600	650	700	750	800	850	900	950
.02	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450
.03	1500	1550	1600	1650	1700	1750	1800	1850	1900	1950
.04	2000	2050	2100	2150	2200	2250	2300	2350	2400	2450
.05	2500	2550	2600	2650	2700	2750	2800	2850	2900	2950
.06	3000	3050	3100	3150	3200	3250	3300	3350	3400	3450
.07	3500	3550	3600	3650	3700	3750	3800	3850	3900	3950

TABLE I.—(continued). *Additions for Manganese.*

Man.	Lbs.	Man.	Lbs.	Man.	Lbs.	Man.	Lbs.	Man.	Lbs.	Man.	Lbs.
		.21	5020	.31	7080	.41	8740	.51	10,000	.61	11,000
		.215	5130	.315	7170	.415	8810	.515	10,050	.615	11,050
		.22	5240	.32	7260	.42	8880	.52	10,100	.62	11,100
		.225	5350	.325	7350	.425	8950	.525	10,150	.625	11,150
		.23	5460	.33	7440	.43	9020	.53	10,200	.63	11,200
		.235	5570	.335	7530	.435	9090	.535	10,250	.635	11,250
		.24	5680	.34	7620	.44	9160	.54	10,300	.64	11,300
		.245	5790	.345	7710	.445	9230	.545	10,350	.645	11,350
.15	3600	.25	5900	.35	7800	.45	9300	.55	10,400	.65	11,400
.155	3720	.255	6000	.355	7880	.455	9360	.555	10,450	.655	11,450
.16	3840	.26	6100	.36	7960	.46	9420	.56	10,500	.66	11,500
.165	3960	.265	6200	.365	8040	.465	9480	.565	10,550	.665	11,550
.17	4080	.27	6300	.37	8120	.47	9540	.57	10,600	.67	11,600
.175	4200	.275	6400	.375	8200	.475	9600	.575	10,650	.675	11,650
.18	4320	.28	6500	.38	8280	.48	9660	.58	10,700	.68	11,700
.185	4440	.285	6600	.385	8360	.485	9720	.585	10,750	.685	11,750
.19	4560	.29	6700	.39	8440	.49	9780	.59	10,800	.69	11,800
.195	4680	.295	6800	.395	8520	.495	9840	.595	10,850	.695	11,850
.20	4800	.30	6900	.40	8600	.50	9900	.60	10,900	.70	11,900
.205	4920	.305	6990	.405	8670	.505	9950	.605	10,950	.705	11,950

on Sheared Plates.

Analysis. Per cent. S.	P.	Mn.	Ult. Strength estimated.	Differences.
.033	.030	.375	51,800	+ 2150
.046	.030	.378	52,998	+ 3682
.033	.015	.345	50,910	— 1810
.035	.015	.350	51,100	+ 570
.037	.015	440	52,560	— 3540
.065	.015	.612	55,820	— 4650
.047	.020	.250	50,200	+ 990
.041	.020	.323	51,314	+ + 436
.069	.020	.270	51,700	+ 490
.039	.020	.345	51,610	— 1060
.061	.020	.385	53,360	— 200
.029	.025	.453	53,136	+ 2374
.026	.030	.310	51,130	+ 710
.060	.030	.255	51,750	— 90
.046	.030	.273	51,410	+ 1870
.059	.030	.405	54,370	— 1410
.075	.030	.410	55,240	— 2400
.033	.035	.560	55,300	+ 1600
.033	.040	.395	53,720	+ 3700
.039	.040	.355	53,380	— 1210
.038	.040	.295	52,250	+ 80
.074	.045	.155	51,370	— 1620
.064	.045	.380	55,490	— 2530
.063	.055	.320	55,160	+ 2130
.031	.060	.328	54,104	— 954
.064	.005	.230	50,210	— 2590
.046	.015	.305	51,640	— 540
.067	.015	.340	53,320	— 510
.021	.015	.355	51,280	— 1830
.036	.015	.360	52,110	— 2750
.040	.015	.385	52,710	— 3540
.055	.015	.383	53,428	— 2918
.034	.015	.440	53,210	— 1140
.045	.015	.490	54,380	— 3370
.045	.015	.520	54,700	+ 2010
.032	.020	.260	50,450	— 320
.043	.025	.415	54,110	— 1330
.037	.025	.235	50,570	+ 1200
.064	.025	.518	56,430	— 2920
.037	.030	.370	53,520	— 1730
.049	.030	.380	54,280	— 2550
.045	.030	.385	54,160	+ 3610
.046	.030	.188	50,360	— 2680
.063	.030	.270	53,000	— 3280
.055	.030	.545	56,650	— 330
.044	.030	.380	54,030	+ 1220
.046	.035	.590	57,050	+ 890
.021	.035	.500	54,900	+ 3350
.053	.035	.360	54,560	— 1690
.043	.035	.503	56,030	+ 1240
.040	.035	.355	53,830	— 2460
.041	.035	.495	55,840	+ 2080
.050	.040	.520	56,950	— 3620
.064	.040	.515	57,600	+ 660
.035	.040	340	53,720	+ 1060
.025	.045	.425	54,950	— 2950
.036	.045	.450	55,850	+ 1910
.064	.045	.290	54,650	+ 1440
.044	.045	.330	54,390	+ 1670
.039	.050	.380	55,380	+ 1740
.039	.050	.382	55,412	+ 1778
.044	.050	.505	57,300	+ 1240
.040	.050	.590	57,950	— 2290
.043	.060	.440	57,260	— 950
.039	.060	.470	57,440	+ 830
.059	.060	.460	58,320	+ 210
.068	.065	.510	59,750	+ 1280
.070	.075	.305	57,640	+ 5520
.041	.080	.340	57,220	+ 1020
.031	.005	.265	50,150	+ 3360
.044	.010	.503	54,980	— 2100



Mn.	Ult. Strength estimated.	Differences.
.570	56,950	+ 2560
.580	57,600	— 4400
.475	55,330	+ 3440
.393	54,338	+ 2482
.380	56,030	— 4810
.600	58,100	+ 620
.315	53,670	+ 3860
.308	52,804	— 1154
.425	56,850	— 1170
.328	53,800	— 1000
.540	57,700	— 870
.325	54,400	+ 3950
.375	56,900	+ 3260
.595	58,350	+ 2030
.563	59,730	+ 4680
.525	58,850	+ 4230
.505	58,630	— 3610
.525	57,950	+ 3020
.550	59,900	— 1710
.440	57,910	+ 2160
.420	57,130	— 720
.475	58,350	+ 1650
.590	60,000	— 1210
.735	62,150	— 1300
.400	59,850	+ 5250
.505	60,200	+ 150
.585	60,230	— 1310
.629	62,690	— 3110
.480	60,460	— 1960
.365	58,540	+ 2290
.440	61,710	— 2370
.345	60,310	+ 4100
.345	60,560	+ 4040
.320	55,760	— 610
.570	57,450	+ 2960
.385	55,010	+ 1990
.520	59,050	— 1700
.455	59,560	+ 1640
.435	57,540	+ 240
.485	58,770	— 3790
.500	58,300	+ 190
.510	58,750	+ 1590
.363	56,958	+ 272
.545	59,200	— 2270
.370	55,920	— 840
.363	56,758	— 1018
.460	58,870	+ 290
.355	56,830	+ 3030
.570	59,550	— 170
.405	57,620	— 1440
.395	56,870	+ 1080
.528	58,780	— 600
.630	62,300	— 1440
.465	60,030	+ 30
.445	59,530	— 950
.470	58,790	+ 1430
.338	57,484	+ 1276
.422	59,308	+ 142
.475	59,950	— 300
.482	58,932	— 1132
.315	58,820	— 1180
.565	61,650	— 90
.640	61,350	— 4180
.513	61,830	+ 1940
.585	62,150	— 3340
.408	58,462	+ 1828
.445	59,530	+ 4630
.428	59,292	— 522
.422	60,080	+ 1440
.475	62,700	— 2640
.488	61,356	+ 3364

ACTER OF STEEL.

(Continued).

ANALYSIS. Per cent.			Ult. Strength estimated.	Differences.
S.	P.	Mn.		
.068	.070	.333	60,644	+ 6996
.043	.070	.405	60,570	+ 3600
.044	.075	.440	61,610	+ 1650
.043	.080	.483	62,602	— 1352
.053	.080	.485	63,120	+ 1700
.065	.090	.425	63,950	+ 2960
.068	.095	.380	63,930	+ 1900
.033	.015	.440	56,010	+ 3820
.048	.020	.735	60,400	— 900
.050	.020	.573	58,880	— 1910
.033	.026	.378	56,308	+ 402
.035	.030	.340	56,220	+ 2460
.076	.030	.495	60,490	— 5480
.066	.030	.355	58,030	— 630
.040	.035	.390	57,840	— 5140
.062	.035	.410	59,240	— 660
.040	.040	.540	60,250	— 1840
.052	.040	.335	58,080	+ 2900
.063	.040	.560	61,600	— 2580
.057	.045	.630	62,550	+ 1860
.059	.045	.525	61,600	— 500
.075	.050	.393	61,288	+ 112
.038	.050	.585	61,700	— 1750
.079	.050	.310	60,620	+ 4700
.012	.051	.363	57,768	— 2358
.025	.056	.552	61,380	— 4830
.069	.060	.585	64,350	+ 1770
.036	.060	.422	60,858	+ 972
.043	.065	.465	62,330	— 880
.032	.065	.505	62,250	— 370
.043	.070	.545	63,650	+ 4040
.065	.070	.475	64,100	+ 3420
.067	.070	.470	64,140	+ 2540
.066	.070	.435	63,640	+ 70
.054	.075	.428	63,492	+ 2988
.043	.080	.465	63,980	+ 1240
.070	.080	.370	63,970	— 3110
.073	.085	.397	65,102	— 1692
.066	.090	.555	67,200	— 1670
.042	.095	.562	66,670	+ 5590
.062	.095	.495	66,940	+ 4190
.035	.015	.525	58,050	— 2310
.047	.025	.378	57,948	+ 1022
.058	.025	.525	60,400	+ 280
.051	.030	.410	59,240	— 1870
.041	.035	.395	59,120	+ 780
.043	.035	.398	59,268	+ 612
.060	.035	.490	61,330	— 1790
.052	.035	.558	61,630	— 620
.079	.045	.298	60,460	+ 4090
.059	.050	.495	63,140	+ 2820
.060	.050	.563	63,980	— 3380
.056	.055	.495	62,590	+ 2130
.062	.055	.510	64,050	+ 7570
.060	.059	.478	64,186	+ 154
.050	.060	.688	65,830	+ 60
.072	.065	.568	66,330	+ 470
.077	.065	.550	66,400	+ 2460
.048	.085	.415	65,760	— 4470
.079	.090	.490	68,880	+ 1220
.025	.021	.450	58,480	— 2290
.053	.025	.475	60,650	+ 6150
.047	.030	.500	61,300	+ 220
.050	.035	.448	61,502	+ 6088
.067	.050	.415	63,810	+ 90
.075	.065	.508	67,330	+ 4170
.071	.070	.500	67,700	+ 5700
.058	.080	.430	67,470	+ 5590
.041	.090	.625	70,050	— 2520
.060	.095	.575	71,150	+ 110
.068	.040	.350	62,750	— 950

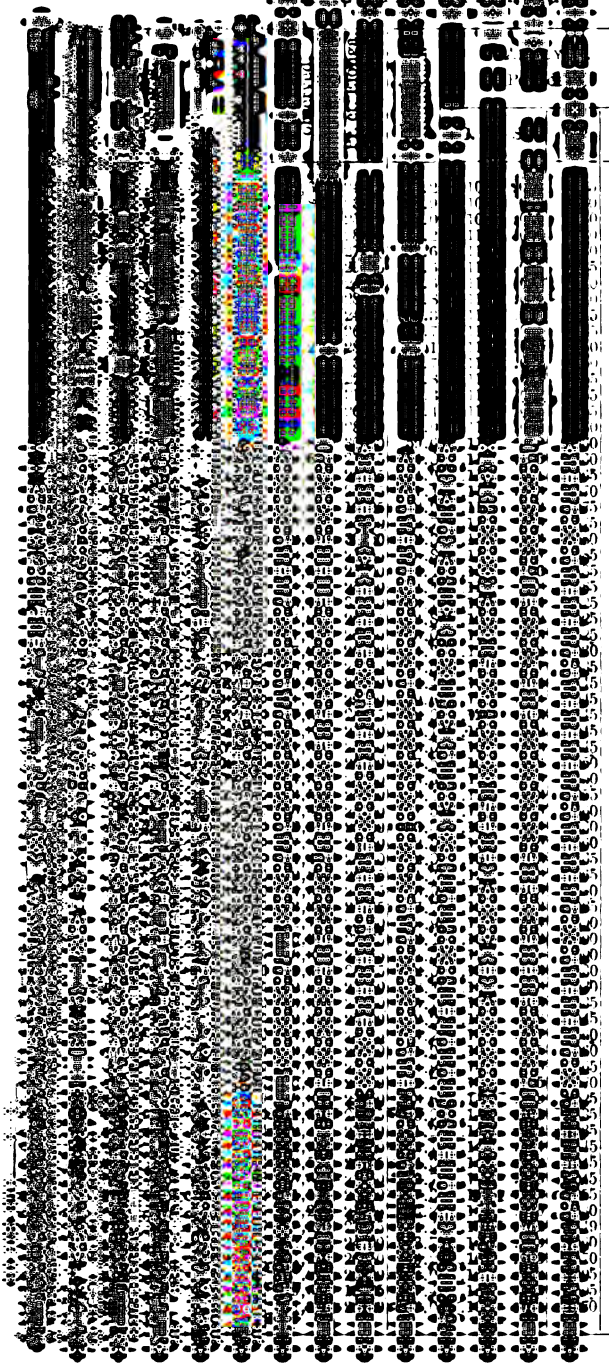
Mn.	Ult. Strength estimated.	Differences.
.425	63,930	+ 7080
.548	64,680	— 220
.333	64,294	+ 806
.545	67,100	+ 4710
.510	68,200	+ 3460
.455	67,130	+ 1510
.295	67,900	— 6400
.450	65,300	+ 2890
.430	65,620	+ 2300
.421	64,794	+ 1430
.415	67,110	— 6580
.485	71,970	+ 470
.288	68,076	+ 5764
.391	63,056	— 6526
.537	67,320	+ 2960
.408	66,842	— 572
.538	70,630	+ 3140
.535	72,950	— 2030
.585	73,450	— 1990
.520	75,050	— 3730
.580	66,900	+ 410
.425	66,000	+ 6760
.652	71,820	+ 390
.630	72,600	— 4240

l Mill Plates.

Mn.	Ult. Strength estimated.	Differences.
.400	51,600	— 520
.230	49,860	+ 40
.310	50,880	+ 2170
.330	53,370	— 1460
.325	51,350	— 1680
.403	53,292	— 2262
.313	51,134	+ 356
.325	52,200	+ 680
.395	53,770	+ 3180
.415	53,860	— 2430
.615	58,800	— 2280
.405	52,620	+ 420
.465	54,730	— 4820
.155	48,420	+ 3220
.365	52,940	+ 2420
.430	53,620	— 2910
.425	53,250	— 710
.270	52,350	— 590
.355	53,330	— 1180
.350	52,400	— 120
.412	55,618	— 5618
.730	57,300	+ 2230
.445	54,840	— 3800
.355	53,830	— 2250
.390	54,190	— 2550
.610	57,150	— 2280
.380	54,680	+ 300
.410	55,640	— 4570
.505	56,300	— 3580

(ntinued).

ANALYSIS. Per cent.			Ult. Strength estimated	Differences.
S.	P.	Mn.		
.063	.040	.510	57,500	+ 1200
.032	.050	.280	53,250	+ 1070
.062	.055	.304	55,622	— 3942
.057	.055	.480	58,060	+ 80
.071	.075	.445	59,930	+ 700
.052	.015	.380	54,180	— 2690
.055	.020	.375	54,700	+ 420
.061	.020	.425	56,390	— 1620
.053	.025	.455	56,210	— 650
.063	.030	.363	55,808	+ 1282
.047	.030	.355	54,880	— 5130
.043	.030	.333	54,294	— 1674
.036	.030	.275	52,850	— 550
.057	.040	.665	59,950	— 700
.044	.040	.640	59,050	— 110
.058	.045	.365	56,940	— 1900
.018	.045	.507	58,120	+ 480
.046	.050	.355	56,630	+ 1690
.060	.050	.410	58,190	— 1550
.053	.050	.588	59,880	+ 440
.036	.050	.348	56,014	+ 386
.038	.050	.430	57,370	+ 6140
.067	.050	.370	57,920	+ 4920
.033	.050	.735	60,350	+ 4480
.042	.050	.445	57,780	+ 1810
.057	.050	.460	58,720	— 5410
.063	.060	.200	55,300	+ 2180
.041	.060	.535	59,650	— 4390
.031	.065	.515	59,400	— 1080
.059	.065	.480	60,410	+ 3330
.070	.070	.505	61,700	— 1170
.077	.075	.325	59,900	+ 5860
.050	.080	.415	60,880	— 2770
.063	.080	.650	63,770	+ 390
.055	.080	.295	58,700	+ 5340
.048	.085	.603	62,930	— 3360
.052	.090	.380	60,980	+ 1990
.038	.090	.558	62,430	— 1450
.063	.005	.510	56,400	— 30
.053	.020	.525	57,550	— 3860
.077	.025	.570	59,700	+ 1200
.051	.025	.458	57,196	+ 564
.005	.025	.400	54,100	+ 6960
.055	.030	.365	56,540	+ 4280
.070	.030	.478	58,886	+ 3934
.069	.030	.583	59,930	— 770
.055	.035	.528	59,180	— 1180
.050	.035	.465	58,230	— 1460
.051	.040	.373	57,468	+ 1452
.066	.040	.410	58,790	+ 4300
.053	.040	.635	60,659	— 3620
.050	.040	.465	58,730	— 1410
.058	.040	.350	57,450	+ 1540
.041	.045	.435	58,390	— 390
.050	.045	.513	58,780	— 2020
.054	.045	.395	58,470	— 250
.049	.050	.480	59,860	— 3550
.035	.050	.480	59,160	— 1390
.053	.050	.590	61,200	+ 2380
.055	.055	.650	62,400	— 4640
.070	.060	.660	63,750	— 5560
.072	.060	.498	62,226	+ 3364
.070	.060	.503	62,180	+ 2900
.041	.060	.595	61,650	+ 2010
.060	.060	.510	61,750	+ 1890
.057	.065	.390	60,540	+ 520
.051	.065	.520	61,900	+ 1620
.047	.065	.615	62,650	+ 1530
.065	.070	.400	61,600	+ 4220
.048	.075	.355	60,530	— 4350
.068	.075	.400	62,250	— 2610



Mn.	Ult. Strength estimated.	Differences.
.575	63,850	+ 2810
.515	63,600	+ 2260
.565	65,150	— 810
.335	58,030	— 3220
.373	57,318	— 1478
.475	60,550	— 4100
.518	61,280	+ 3170
.365	58,540	+ 1820
.355	58,480	— 1250
.393	60,238	— 4538
.583	61,580	+ 3670
.610	62,650	+ 290
.590	63,000	— 2560
.605	63,640	— 5080
.538	63,630	+ 1440
.585	64,450	— 3120
.610	63,250	— 5400
.385	60,260	— 750
.297	60,090	— 2660
.453	64,086	+ 1004
.625	66,600	+ 4970
.485	64,470	+ 770
.433	63,212	— 682
.457	63,984	— 584
.435	65,760	+ 1820
.453	65,636	— 936
.505	59,500	— 1370
.268	57,560	— 360
.535	60,750	+ 710
.510	61,050	— 3820
.405	60,770	— 2420
.365	60,490	+ 280
.395	59,970	+ 1250
.385	60,010	— 2190
.380	60,530	— 4150
.410	61,390	— 300
.612	64,170	— 5010
.495	62,840	+ 1670
.585	65,350	— 1800
.513	64,330	— 3930
.448	63,522	+ 468
.460	64,920	+ 3050
.315	62,220	+ 2200
.430	63,170	— 3280
.550	67,100	+ 6900
.485	67,920	— 4600
.545	68,700	+ 4080
.588	69,890	+ 1090
.330	64,940	— 4640
.480	60,860	— 250
.540	62,150	— 1610
.495	61,320	— 1320
.445	62,530	— 3150
.525	66,950	— 2950
.365	63,240	— 3330
.395	65,870	+ 3750
.667	68,570	+ 2170
.290	59,170	+ 900
.610	64,350	— 2690
.360	61,410	— 990
.560	65,950	— 3030
.405	63,370	— 2850
.390	63,590	— 2960
.420	65,530	— 3990
.260	60,850	+ 6390
.436	64,604	— 2384
.533	69,930	+ 2820
.670	72,800	+ 1420
.435	73,470	+ 330
.615	77,050	+ 2550
.490	72,930	+ 1250

TABLE IV.—*Summary of the Differences in the* 408 *Tests of Tables II. and III.*

In the first two columns the effects of sulphur were not considered; in the last two columns the effect of sulphur was estimated at 500 lbs. for each 01 per cent. of S.

	Both Mills.	Old Correction for Size.	Both Mills.	New Correction for Size.
+ over 5000 lbs.....	18	20	18	14
+ 4 to 5000 lbs.....	17	16	18	14
+ 3 " 4000 "	12	24	26	37
+ 2 " 3000 "	31	44	35	42
+ 1 " 2000 "	32	45	53	59
Within ± 1000 lbs.....	116	120	106	116
— 1 to 2000 lbs.....	38	46	54	50
— 2 " 3000 "	58	33	41	38
— 3 " 4000 "	33	28	28	25
— 4 " 5000 "	32	23	18	6
— over 5000 "	21	9	11	7
Total + more than 1000 lbs.	110	149	150	166
" — " " "	182	139	152	126
Difference.....	— 72	+ 10	— 2	+ 40
Per cent. within 1000 lbs...	28.4	29.4	26.0	28.4
" " " 2000 " ...	45 6	51.7	52.2	55.1
" " " 3000 " ...	67.4	70.5	70.8	74.7
" " " 4000 " ...	78.4	83.3	84.1	89.9
" " " 5000 " ...	90.4	92.9	92.9	94 9

New Corrections for Size of Plates.

Plates.	Up to 70 in. Wide.	Over 70 in. Wide.
$\frac{3}{4}$ in. thick and over.....	— 2000 lbs.	— 1000 lbs.
$\frac{11}{16}$ in. " " "	— 1750 "	— 750 "
$\frac{5}{8}$ " " " "	— 1500 "	— 500 "
$\frac{9}{16}$ " " " "	— 1250 "	— 250 "
$\frac{1}{2}$ " " " "	— 1000 "	± 0 "
$\frac{7}{16}$ " " " "	— 500 "	+ 500 "
$\frac{3}{8}$ " " " "	± 0 "	+ 1000 "
$\frac{5}{16}$ " " " "	+ 3000 "	+ 4000 "

TABLE V.—*Summary of Differences for Different Percentages of Carbon, Sulphur, Phosphorus and Manganese.*

CARBON.

	.06		.07		.08		.09		.10		.11		.12		.13		.14		.15		.16		.17		.18		Total.		Total. Both Mills.
	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	
+ Over 5000	.....	.....	.....	.....	...	1	3	1	1	1	...	1	1	1	...	4	...	1	1	1	.....	...	.....	.....	...	1	6	12	18
+ 4 to 5000	.....	.....	.....	.....	.....	.....	2	4	3	1	1	3	1	1	...	1	...	1	.....	.....	.....	.....	.....	.....	.....	.....	7	11	18
+ 3 " 4000	...	1	1	1	1	2	1	6	2	3	2	2	1	...	1	...	...	1	.....	.....	...	1	.....	.....	.....	.....	9	17	26
+ 2 " 3000	1	1	...	2	2	2	1	5	5	2	...	4	1	3	1	...	.....	.....	...	2	1	1	.....	.....	1	...	13	22	35
+ 1 " 2000	.....	.....	...	2	2	11	4	1	6	12	4	2	3	2	.....	.....	...	1	...	1	1	...	.....	.....	1	...	21	32	53
Within ±1000	2	...	2	9	7	9	9	5	7	14	6	10	5	7	1	3	2	3	...	1	1	1	.....	.....	...	2	42	64	106
— 1 to 2000	1	...	1	5	1	6	7	7	4	7	2	6	2	2	2	..	...	...	.....	.....	...	1	.....	.....	.....	.....	20	34	54
— 2 " 3000	.....	.....	3	2	4	9	2	2	2	2	2	2	2	1	1	2	3	...	1	...	...	1	.....	.....	.....	.....	20	21	41
— 3 " 4000	.....	.....	...	1	3	4	1	2	3	2	2	1	3	1	2	...	2	...	.....	.....	.....	.....	...	1	.....	.....	16	12	28
— 4 " 5000	.....	.....	...	1	2	...	1	2	2	1	2	1	4	1	...	...	...	...	.....	.....	.....	.....	.....	.....	...	1	11	7	18
— Over 5000	.....	.....	.....	.....	1	...	2	...	1	...	2	2	.....	.....	.....	.....	...	1	...	1	...	1	.....	.....	.....	.....	6	5	11
Total +	1	2	1	5	5	16	11	17	17	19	7	12	7	7	2	5	0	4	1	4	2	2	...	0	2	1	56	94	150
Total —	1	0	4	9	11	19	13	13	12	12	10	12	11	5	5	2	5	1	1	1	0	3	...	1	0	1	78	79	152
Difference —	0	+ 2	— 3	— 4	— 6	— 3	— 2	+ 4	+ 5	+ 7	— 3	0	— 4	+ 2	— 3	+ 3	— 5	+ 3	0	+ 3	+ 2	— 1	...	— 1	+ 2	0	— 17	+ 15	— 2
Per cent. within 5000																													92.9

TABLE V.—(continued).—*Sulphur.*

	Under .02		.02		.03		.04		.05		.06		.07		Total.		Total. Both Mills
	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	
+ Over 5000	1	...	...	...	1	...	...	1	2	3	...	3	2	5	6	12	18
+ 4 to 5000	...	...	...	...	1	...	...	2	1	...	4	4	1	5	7	11	18
+ 3 to 4000	...	...	...	1	1	5	1	6	2	1	1	2	4	2	9	17	26
+ 2 to 3000	...	...	...	1	2	4	2	4	7	6	1	6	1	1	13	22	35
+ 1 to 2000	...	...	...	1	2	10	4	11	5	4	5	3	5	3	21	32	53
Within ± 1000	...	...	1	2	8	11	6	16	18	10	6	20	3	5	42	64	106
— 1 to 2000	...	...	...	2	4	8	7	7	5	5	2	7	2	5	20	34	54
— 2 to 3000	...	1	1	2	5	2	3	6	6	2	3	5	2	3	20	21	41
— 3 to 4000	...	...	...	...	...	1	7	2	3	3	4	3	2	3	16	12	28
— 4 to 5000	...	...	...	1	...	...	4	2	4	1	1	2	2	1	11	7	18
— Over 5000	...	...	...	...	...	1	2	1	1	1	2	1	1	1	6	5	11
Total +	1	0	0	3	7	19	7	24	17	14	11	18	13	16	56	94	150
Total —	0	1	1	5	9	12	23	18	19	12	12	18	9	13	73	79	152
Difference =	+ 1	— 1	— 1	— 2	— 2	+ 7	— 16	+ 6	— 2	+ 2	— 1	0	+ 4	+ 3	— 17	+ 15	— 2
Per cent. within 5000 =	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	92.9

TABLE V.—(continued).—*Phosphorus.*

	Under .02		.02		.03		.04		.05		.06		.07		.08		.09		Total.		Total. Both Mills.
	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	Uni.	Sh'd.	
+ Over 5000	.....		1	1	1	2	...	1	1	1	...	1	1	3	2	2	...	1	6	12	18
+ 4 to 5000	.....		.....		1	...	1	3	2	3	1	1	1	1	...	2	1	1	7	11	18
+ 3 to 4000	1	2	...	2	2	3	1	5	.....		5	3	...	2	...	...	.....		9	17	26
+ 2 to 3000	...	2	1	3	2	3	...	6	2	3	4	1	2	3	1	...	1	1	13	22	35
+ 1 to 2000	.....		1	3	1	7	5	8	5	6	3	2	3	2	1	2	2	2	21	32	53
Within ± 1000	2	3	12	11	5	16	8	12	4	9	3	10	2	1	5	1	1	1	42	64	106
— 1 to 2000	...	3	4	3	6	8	3	9	4	2	1	5	1	...	...	3	1	1	20	34	54
— 2 to 3000	1	5	2	2	6	5	5	3	2	2	2	1	1	1	1	1	...	1	20	21	41
— 3 to 4000	...	3	1	..	3	2	4	2	3	2	4	1	.....		1	2	.....		16	12	28
— 4 to 5000	1	1	...	2	1	...	3	...	2	2	1	1	1	...	1	1	1	...	11	7	18
— Over 5000	.....		.....		2	3	.....		2	...	2	1	.....		...	1	.....		6	5	11
Total +	1	4	3	9	7	15	7	23	10	13	13	8	7	11	4	6	4	5	56	94	150
Total —	2	12	7	7	18	18	15	14	13	8	10	9	3	1	3	8	2	2	73	79	152
Difference =	— 1	— 8	— 4	+ 2	— 11	— 3	— 8	+ 9	— 3	+ 5	+ 3	— 1	+4	+ 10	+ 1	— 2	+ 2	+ 3	— 17	+ 15	— 2
Per cent. within 5000 =	.....		.....		.....		.....		.....		.....		.....		.....		.....		.....		92.9

TABLE V.—(continued).—*Manganese.*

	Under .20		.20 to .25		.25 to .30		.30 to .35		.35 to .40		.40 to .45		.45 to .50		.50 to .55		.55 to .60		.60 to .65		.65 to .70		.70 to .75		Total.		Total.
	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Both Mills.
+ Over 5000	.....		...	1	2	...	1	2	.....		2	5	...	1	...	2	1	1	.....		.....		.....		6	12	18
+ 4 to 5000	.....		.....		...	1	...	3	2	...	2	1	...	1	1	4	...	1	1	...	.....		1	...	7	11	18
+ 3 to 4000	1	...	.....		...	1	...	2	2	5	...	2	3	3	1	4	2	...	.....		.....		.....		9	17	26
+ 2 to 3000	.....		1	...	.....		2	3	1	3	...	4	1	6	3	2	2	4	1	...	1	...	1	...	13	22	35
+ 1 to 2000	.....		...	1	1	2	...	3	7	7	2	4	3	8	4	5	2	1	1	1	1	...	.....		21	32	53
Within ± 1000	.....		1	...	4	5	3	8	8	10	9	11	7	8	3	11	3	7	2	1	2	2	...	1	42	64	106
— 1 to 2000	...	1	.....		.....		3	5	4	6	2	6	4	4	5	2	2	8	...	1	.....		...	1	20	34	54
— 2 to 3000	...	1	...	1	1	...	.....		5	6	8	3	...	2	2	5	1	2	3	1	.....		.....		20	21	41
— 3 to 4000	.....		.....		...	1	2	...	1	1	4	2	1	2	4	3	2	2	2	1	.....		.....		16	12	28
— 4 to 5000	.....		.....		.....		1	...	3	2	1	...	3	...	1	...	...	2	1	3	1	...	.....		11	7	18
— Over 5000	.....		.....		...	1	.....		1	2	1	1	1	1	.....		.....		2	...	1	...	.....		6	5	11
Total +	1	0	1	2	3	4	3	13	12	15	6	16	7	19	9	17	7	7	3	1	2	..	2	0	56	94	150
Total —	0	2	0	1	1	2	6	5	14	17	16	12	9	9	12	10	5	14	8	6	2	...	0	1	73	79	152
Difference =	+ 1	— 2	+ 1	+ 1	+ 2	+ 2	— 3	+ 8	— 2	— 2	— 10	+ 4	— 2	+ 10	— 3	+ 7	+ 2	— 7	— 5	— 5	0	...	+ 2	— 1	— 17	+ 15	— 2
Per cent. within 5000 =	.....		.....		.....		.....		.....		.....		.....		.....		.....		.....		.....		.....		.....		92.9

TABLE VI.—*Summary of Differences for Different Thicknesses of Plates and Ultimate Strength.*

46,000 to 54,000 Pounds.

	5/16" to 3/8"		3/8" to 1/2"		1/2" to 5/8"		5/8" to 3/4"		3/4" to 7/8"		7/8" to 1"		Total.		Total, Both Mills.
	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	
+ Over 5000	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
+ 4 to 5000	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
+ 3 to 4000	...	...	...	1	1	...	...	...	...	...	...	...	1	1	2
+ 2 to 3000	...	...	...	...	1	1	...	...	...	...	...	...	1	1	2
+ 1 to 2000	...	...	...	1	...	...	...	...	...	1	...	...	...	2	2
Within ± 1000	...	1	...	10	3	2	5	...	1	...	...	...	9	13	22
− 1 to 2000	...	...	...	8	...	1	4	2	...	...	...	...	4	11	15
− 2 to 3000	...	...	1	8	3	2	1	1	...	...	1	...	6	11	17
− 3 to 4000	...	...	3	4	1	1	...	...	...	...	...	...	4	5	9
− 4 to 5000	...	...	...	2	1	1	1	...	...	...	...	...	2	3	5
− Over 5000	...	...	...	1	...	...	2	...	1	...	...	...	3	1	4
Total +	...	...	0	2	2	1	0	0	0	1	0	...	2	4	6
Total −	...	...	4	23	5	5	8	3	1	0	1	...	19	31	50
Difference −	...	...	− 4	− 21	− 3	− 4	− 8	− 3	− 1	+ 1	− 1	...	− 17	− 27	− 44
Per cent. within 5000 −	...	...	...	...	...	...	...	...	...	...	...	...	...	...	94.9

TABLE VI.—(continued).—54,000 *to* 62,000 *Pounds.*

	⅛" to ⅜"		⅜" to ½"		½" to ⅝"		⅝" to ¾"		¾" to ⅞"		⅞" to 1"		Total.		
	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Total. Both Mills.
+ Over 5000	...	...	1	...	...	...	...	...	...	...	...	...	1	...	1
+ 4 to 5000	...	...	1	..	...	...	...	...	1	...	...	...	2	...	2
+ 3 to 4000	...	3	1	7	...	...	...	1	...	...	...	...	1	11	12
+ 2 to 3000	...	2	2	9	...	...	1	1	1	...	...	...	4	12	16
+ 1 to 2000	...	2	1	14	4	4	2	1	2	...	1	...	10	21	31
Within ± 1000	...	...	7	25	10	11	3	2	2	1	2	...	24	39	63
— 1 to 2000	...	...	2	12	6	4	2	...	2	3	3	...	15	19	34
— 2 to 3000	...	...	3	6	3	...	2	2	2	...	2	...	12	8	20
— 3 to 4000	...	1	1	3	7	2	1	...	1	...	1	...	11	6	17
— 4 to 5000	1	...	2	1	1	2	1	...	...	...	3	...	8	3	11
— Over 5000	...	...	1	1	1	...	1	1	...	...	...	1	3	3	6
Total +	0	7	6	30	4	4	3	3	4	0	1	0	18	44	62
Total —	1	1	9	23	18	8	7	3	5	3	9	1	49	39	88
Difference —	— 1	+ 6	— 3	+ 7	— 14	— 4	— 4	0	— 1	— 3	— 8	— 1	— 31	+ 5	— 26
Per cent. within 5000 —	...	...	...	...	...	...	...	...	...	...	...	...	...	...	96.7

TABLE VI.—(continued).—62,000 *to* 70,000 *Pounds.*

	1/8" to 5/8"		5/8" to 1/2"		1/2" to 5/8"		5/8" to 3/4"		3/4" to 7/8"		7/8" to 1"		Total.		Total. Both Mills.
	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	
+ Over 5000	2	...	...	4	.....		1	1	1	...	.....		4	5	9
+ 4 to 5000	2	2	1	5	...	1	.....		.....		.....		3	8	11
+ 3 to 4000	.....		3	3	3	...	1	...	.....		.....		7	3	10
+ 2 to 3000	.....		2	5	1	1	2	2	.....		.....		5	8	13
+ 1 to 2000	.....		6	7	1	...	...	1	.....		1	...	8	8	16
Within ± 1000	...	1	3	5	4	3	.....		1	...	.....		8	9	17
− 1 to 2000	.....		1	3	.....		.....		.....		.....		1	3	4
− 2 to 3000	.....		.....		1	1	.....		.....		1	...	2	1	3
− 3 to 4000	.....		1	...	.....		.....		.....		.....		1	...	1
− 4 to 5000	.....		.....		.....		.....		1	1	.....		1	1	2
− Over 5000	.....		.....		.....		...	1	.....		.....		...	1	1
Total +	4	2	12	24	5	2	4	4	1	0	1	...	27	32	59
Total −	0	0	2	3	1	1	0	1	1	1	1	...	5	6	11
Difference −	+ 4	+ 2	+ 10	+ 21	+ 4	+ 1	+ 4	+ 3	0	− 1	0	...	+ 22	+ 26	+ 48
Per cent. within 5000 −	.....		.....		.....		.....		.....		.....		.....		88.5

TABLE VI.—(continued).—*Over* 70,000 *Pounds.*

	1/16" to 3/8"		3/8" to 1/2"		1/2" to 5/8"		5/8" to 3/4"		3/4" to 7/8"		7/8" to 1"		Total.		
	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Total. Both Mills.
+ Over 5000	...	3	1	3	...	1	.....	.....	.....	.....	.....	.....	1	7	8
+ 4 to 5000	2	1	...	2	.....	.....	.....	.....	.....	.....	.....	.....	2	3	5
+ 3 to 4000	...	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	...	2	2
+ 2 to 3000	.....	.....	3	1	.....	.....	.....	.....	.....	.....	.....	.....	3	1	4
+ 1 to 2000	.....	.....	1	1	1	...	1	...	.....	.....	.....	.....	3	1	4
Within ± 1000	...	1	...	2	1	...	.....	.....	.....	.....	.....	.....	1	3	4
— 1 to 2000	.....	.....	.....	.....	...	1	.....	.....	.....	.....	.....	.....	...	1	1
— 2 to 3000	.....	.....	.....	.....	...	1	.....	.....	.....	.....	.....	.....	...	1	1
— 3 to 4000	.....	.....	.....	.....	...	1	.....	.....	.....	.....	.....	.....	...	1	1
— 4 to 5000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	...
— Over 5000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	...
Total +	2	6	5	7	1	1	1	...	.....	.....	.....	.....	9	14	23
Total —	0	0	0	0	0	3	0	...	.....	.....	.....	.....	0	3	3
Difference =	+ 2	+ 6	+ 5	+ 7	+ 1	— 2	+ 1	...	.....	.....	.....	.....	+ 9	+ 11	+ 20
Per cent. within 5000 =	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	73.3

TABLE VI.—(continued).—46,000 *to* 78,000 *Pounds.*

	1/16" to 5/16"		3/8" to 1/2"		1/2" to 5/8"		5/8" to 3/4"		3/4" to 7/8"		7/8" to 1"		Total.		Total. Both Mills.
	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	Universal.	Sheared.	
+ Over 5000	2	3	2	7	...	1	1	1	1	...	.....		6	12	18
+ 4 to 5000	4	3	2	7	...	1	.....		1	...	.....		7	11	18
+ 3 to 4000	...	5	4	11	4	...	1	1	.....		.....		9	17	26
+ 2 to 3000	...	2	7	15	2	2	3	3	1	...	.....		13	22	35
+ 1 to 2000	...	2	8	23	6	4	3	2	2	1	2	...	21	32	53
Within ± 1000	...	3	10	42	18	16	8	2	4	1	2	...	42	64	106
− 1 to 2000	.....		3	23	6	6	6	2	2	3	3	...	20	34	54
− 2 to 3000	.....		4	14	7	4	3	3	2	...	4	...	20	21	41
− 3 to 4000	...	1	5	7	8	4	1	...	1	...	1	...	16	12	28
− 4 to 5000	1	...	2	3	2	3	2	...	1	1	3	...	11	7	18
− Over 5000	.....	.....	1	2	1	...	3	2	1	...	...	1	6	5	11
Total +	6	15	23	63	12	8	8	7	5	1	2	0	56	94	150
Total −	1	1	15	49	24	17	15	7	7	4	11	1	73	79	152
Difference −	+ 5	+ 14	+ 8	+ 14	− 12	− 9	− 7	0	− 2	− 3	− 9	− 1	− 17	+ 15	− 2
Per cent. within 5000 −	.....		.....		.....		.....		.....		.....		.....		92.9

THE CONSUMPTION OF FUEL IN THE TAYLOR GAS-PRODUCER PLANTS AT THE ASPEN AND MARSAC MILLS COMPARED.

BY C. A. STETEFELDT, OAKLAND, CAL.

(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

IT will be of interest to compare the statistics of the gas-producer plant at Aspen, Colorado (recorded by Mr. W. S. Morse in a paper read at the Montreal Meeting, February, 1893*), with those at the Marsac mill, Park City, Utah, where such a plant was first introduced by the writer in July, 1890. In both mills a Stetefeldt furnace is used for roasting; but the Marsac mill has the old-fashioned revolving dryers, while at Aspen, shelf-dryers are at hand. At Aspen, separate Taylor-producers are provided for the Stetefeldt furnace and the shelf-dryers; at the Marsac mill one 7-foot producer supplies gas to both the furnace and the dryers. Hence, in the latter case, the quantity of coal consumed for each apparatus can only be estimated, based upon the relative consumption of wood before gas was introduced. According to Mr. Wilson's statement, the relative consumption of wood in the Stetefeldt furnace and the revolving dryers was as 3 to 2.

In the year 1892 the Marsac mill put through the dryers and the Stetefeldt furnace the following quantities of ore and salt (approximate dry weights): ore, 22,800 tons; salt, 2262 tons. There were consumed in the Taylor-producer 2,714 tons of Rock Springs coal. We may thus make the comparative estimate as follows:

Table Showing the Consumption of Coal per Ton of Ore and Salt at the Marsac and Aspen Mills.

	Marsac. Pounds.	Aspen. Pounds.	Difference. Pounds.
Drying ore and salt, ...	86.63	72.22	14.41
Roasting ore, ...	142.40	117.44	24.96
Total, ...	229.03	189.66	39.37

In making a just comparison a number of items must be taken

* *Trans.*, xxi., 919.

into consideration—for all of which I cannot give perfectly accurate figures—namely, the quality of the coal, the percentage of moisture in ore and salt, the percentage of sulphur in the ore, the number of tons of ore roasted in 24 hours, and the efficiency of the two systems of dryers.

The coal consumed at the Aspen and Marsac mills has the following composition:

	Aspen. Average of ⅓ Sunshine and ⅔ New Castle. Coal.	Marsac. Rock Springs Coal.
	Per cent.	Per cent
Water,	2.0	7.0
Volatile matter,	37.4	36.0
Fixed carbon,	44.8	53.3
Ash,	15.7	3.5
Fixed carbon and volatile matter,	82.2	89.3

It will be seen that the calorific effect of the fuel used must be nearly the same at both mills. Although the Rock Springs coal is by 7 per cent. richer in fixed carbon and hydro-carbons, it carries 5 per cent. more water than the coal used at Aspen.

Mr. Morse gives the moisture at Aspen for ore at 6.15 per cent., and for salt at 1.0 per cent. Accurate statistics regarding moisture *in* the ore reduced at the Marsac mill are entirely wanting. The shipping-ore, according to Mr. Lamb, contained 8.4 per cent. moisture for 1892; and since their ore goes to the sampling-works directly from the mine, while the milling-ore often remains for months in the ore-houses, it is fair to assume that the milling-ore contained less moisture, which would make it practically the same as that recorded for Aspen ore.

A considerable difference exists regarding the contents of sulphur in the ores treated, Aspen ore containing 8.1 per cent. and Marsac ore much less. An analysis of an average battery-sample for 1891 gave only 0.7 per cent. of sulphur for Marsac ore. For the out-put of 1892 no sulphur determination has been made, but since the ore of 1892 came from the lower levels of the Daly mine, it is fair to assume that the percentage of sulphur was somewhat higher. The percentage of sulphur is slightly increased by adding pulverized sulphur to the battery-pulp before roasting. This, however, is not always done. During 1892, Mr. Lamb says, the average consumption of sulphur in this way per ton of ore was only 3.72 pounds.

The number of tons of ore roasted in 24 hours also plays an im-

portant part in the consumption of fuel, an increased output requiring less coal in proportion. The Marsac furnace roasted from 60 to 70 tons of ore in 24 hours, while at Aspen as much as 90 tons was put through.

That the shelf-dryers are more economical in fuel than the revolving dryers is self-evident. The ore remains longer in its passage through the former, and the latter lose a large amount of heat by radiation.

All these facts help to explain the difference in the consumption of fuel in the two plants.

The suggestion of Mr. Morse, to provide better facilities for cleaning the gas-pipes of tar and soot, has been followed by the writer in designing the gas-plants for the Lehi and Ontario mills. He has also substituted spiral-weld steel tubes for riveted sheet-iron pipes. A part of the latter have been replaced by the former in the Marsac plant, and the result has been favorable. For insulating the gas-tubes in the Ontario plant, they will be covered first with thin corrugated sheet-iron, over which a coating of asbestos-magnesia will be spread. The insulation by troughs of sheet-iron filled with mineral wool was used at the Marsac and Aspen mills on account of cheapness.

Lining iron pipes with fire-clay tiles, which is the old method, is not feasible for long pipes of 20 inches and less diameter. Besides, such pipes (which in this instance must be suspended above the floor) would be very heavy. With improved cleaning-facilities, the removal of tar and soot is quickly accomplished, and there is then little danger of over-heating or burning the pipes. The spiral-weld steel tubes also bear greater heat without injury, especially since they are without riveted joints.

The low consumption of fuel at Aspen for the chloridizing-roasting of silver-ores is phenomenal in metallurgical history.

In conclusion, the writer would observe that Mr. Morse experienced the same difficulty in running the Taylor gas-producers with coal leaving light and infusible ashes (using Sunshine coal alone) as was found in starting the producer at the Marsac mill with coal mined at Coalville, Utah. For this reason the Marsac producer is supplied with the dearer Rock Springs coal. This difficulty had previously not been encountered by Mr. Taylor in the East.

THE LIMITATIONS OF THE GOLD STAMP-MILL.

BY T. A. RICKARD, DENVER, COLORADO.

(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

MILLING is one of the metallurgical arts whereby the extraction of the largest possible proportion of the value in an ore is effected at the least possible expense. Stamp-milling* is that particular process in which a heavy body of iron is caused to fall upon the ore so as to disintegrate it and thereby induce a separation between what is valuable and what is worthless. The latter is usually less in specific gravity, and is therefore, by the further aid of water, removed from the former, which is then collected by the use of mercury.

Several similes have been employed to describe this process. The stamp has been likened to a hammer of which the stem is the handle and the die the anvil. The ore upon which the stamp falls has been compared to a nut awaiting the descent of the hammer whose blow is to separate the valueless shell, the quartz, from the valuable kernel, the gold.

When we begin to pursue our inquiries, however, we find that the analogy is just sufficiently true to emphasize the departures from it. The hammer falls, the anvil is fixed; so with the stamps and the mortar. The anvil is made of softer metal than the hammer; so also the die is often, and should be always, of steel or iron less hard and more tough than that of the shoe. The movement of the hammer and the drop of the stamp are both intermittent.

In regard to their intermittent action, as in many other respects, stamp-mills arrange themselves under two types, which, though apparently contradictory, have both been evolved from a common original, and are united by a great variety of intermediate modifications. The slow speed and the high drop of the mills of Gilpin county Colorado, appear to have very little in common with the fast speed and short drop of those of the main gold belt of California; yet the practice of the one was largely derived from that of the other,

* I shall confine the discussion to simple gold stamp-milling.

and each has been adapted to the treatment of the ores of its particular region.

The first and most apparent difference is that of speed. In Colorado the drop is regulated at 30 per minute, while in California it averages from 90 to 105. The more rapid drop gives a less intermittent action, and in this respect more nearly approaches the ideal machine.

The work done by the hammer is, however, dependent not only on the rapidity of its blows but also upon its weight and the distance through which it falls. Keeping to the two types, which we have chosen as representatives of the two systems of milling, we find that in Colorado the stamp weighs 550 to 600 pounds and falls a height of 18 to 20 inches, while in California the stamp weighs from 750 to 850 pounds and drops only 4 to 6 inches. Upon multiplication of these three factors—weight, drop, and speed—we find that the theoretical work done is nearly equal and is about one horse-power.

In milling, however, the efficiency of the stamp as a crushing machine is gauged by the quantity of ore which it can reduce, and we find that this does not at all correspond to the theoretical equality of the mills. In Colorado the stamp crushes 1 ton per twenty-four hours, while in California, with an ore of similar hardness, the amount is from two and a half to three times as much. Why is this difference? To explain it we must suppose the hammer to fall not upon the dry and wide surface of an anvil, but upon a face of iron confined within a narrow box and under water. This box corresponds to the mortar or coffer of the stamps. It has no opening* save in front, where a metallic grating or screen permits the escape of only that part of the material which has been crushed sufficiently small to pass through the openings. The ore upon the die is under water. The depth of that water depends upon the level of the bottom of the aperture occupied by the screen-frame. In Colorado the depth of discharge, as measured by the distance from the bottom of the screen to the top of the die, is 14 inches, but in California it is 4 inches only.† Herein lies the key to the difference in the crushing capacity of the two mills. Though the same amount of power be expended, and though the screen used be of similar mesh, yet in the Colorado mill the stamp falls through 10

* The feed-hole is higher up and does not concern us here.

† In making the comparison between the two systems of milling, I have purposely chosen extreme types.

inches more of water and has to discharge the pulp at a level 10 inches higher than in the California mill. The greater depth of discharge deadens the effectiveness of the blow of the stamp and weakens the force of the splash. Another result is obtained. While the screen does not in either case succeed in sizing the material discharged through it, yet it will be found that, though provided with similar screens, the pulp issuing from the deep mortar has a fineness much greater than that discharged by the shallow one. The pulverized ore is retained by the deep mortar long after its particles have been crushed to a size permitting their passage through the screen-openings, and they therefore become repulverized to a further degree of fineness.

This touches upon one of the points in respect of which the stamp-mill is most faulty. By actual test it is found that, though using a 40-mesh screen, for instance, with the theoretical supposition of crushing to that particular size, yet in a Colorado mill fully 70 per cent. of the pulp, and in a California battery about 50 per cent., will pass through a 100-mesh sieve. The percentage varies with the character of the ore, but these figures may be considered fairly representative. Two causes are chiefly responsible for this. The most important in its effects is the pause which occurs between the successive drops of the stamp. In a Colorado mill the interval is two seconds; in California it varies from three-fifths to two-thirds of a second. Particles of ore, which have been pulverized to a fineness which would permit of their exit through the screen, are enabled to settle towards the bottom of the mortar. It would be expected that the heavy metallic minerals occurring in the ore would, because of their greater specific gravity, be most affected by this feature of the treatment. In practice this is found to be so. The fine slimes contain a large proportion of metallic sulphides, generally valuable on account of their close association with the precious metals, while the coarsest particles to be found in the tailings usually consist of quartz and other minerals forming the less heavy gangue.

The want of any proper control over the regular sizing of the pulp is also due to the unequal and irregular splash of the water in the battery and the hap-hazard way in which the particles of pulverized ore strike against the screen. In the case of any single particle, for instance, it is a question of hit-or-miss whether it be thrown against an opening or a blank. If it fail to pass through, it is thrown back by the recession of the water and undergoes a further agitation and probable pulverization.

In practice this feature of the stamp-mill is recognized by both the California and the Colorado millman. On the Pacific coast the mortars are made narrow, thereby diminishing the opportunities for the settling of the particles of ore, and, by increasing the force of the splash, adding to the chances of its exit through the screen. In late years there has also been a tendency to use wire-cloth in place of punched iron, for the reason that the former, though having openings of identical size, yet has more of them per square inch than the latter, and, therefore, presents a greater area of discharge. By giving an inclination of 10 degrees to the screen-frame, the exit of the pulp is further assisted.

In Colorado, this defect of the stamp-mill has been utilized, and has been made an assistant to the millman. The mortars of this district are wide and roomy, the splash of the water inside the battery is weak, and the pulp remains inside until pulverized to a fineness much exceeding that required for its passage through the screen. There is a reason for this apparently contradictory feature of the milling practice. To explain it we must glance at the ore. We find it to contain an average of 15 per cent. of pyrite. The gold is very fine and intimately associated with the pyrite. To separate them it is necessary not only to crush to a certain degree of fineness, but also to obtain conditions which will permit the gold when once separated to settle upon amalgamated plates placed inside. The deep discharge causes the pyrite to remain in the mortar-box long after it has been pulverized to a size smaller than the screen-openings; the long drop gives the interval of time required to allow of the settling of the fine gold, while the roomy character of the mortar aids the deep discharge in affording a chance for the gold to get out of the way of the falling stamps and to become amalgamated upon the two copper plates inserted at the back and front of the mortar. In this way about two-thirds of the total yield of amalgam is obtained inside the mortar. In California the introduction of plates is not admissible, in mortars having so shallow a discharge as 4 inches, because the more constant and more violent agitation of the pulp prevents the settlement of the gold and would cause the abrasion or "scouring" of the surface of amalgamated plates. A certain varying percentage of gold is, indeed, usually arrested inside, partly by the aid of mercury added to the ore as it is fed into the battery, but this is of such a coarseness that gravity alone would serve to keep it within the mortar.

We have now entered into the discussion of the effects produced by the action of the stamp upon the ore. In many respects it departs from the analogy of the hammer which cracks open a nut. While being lifted the stamp also turns. This is effected by the friction of the cam-surface against the under side of the tappet. In a slow-drop mill the stamp makes a complete turn each time it is lifted, but with an increased speed this action is more uncertain and from 4 to 10 drops are required to make a whole revolution.

This feature of the stamp-mill breaks the analogy to the hammer and anvil, and causes it to resemble the pestle and mortar. The turning of the stamp in rising is communicated to the ore when it falls and induces a grinding-action, which has important results. The mere impact of the stamp upon the particles of gold has the effect of hammering it, of increasing its density and of preventing its amalgamation, while the turning of the shoe upon the die causes the abrasion of the surface of the gold and the rubbing off of any film of foreign matter, which, by preventing contact between the gold and the mercury, is prejudicial to amalgamation. In grinding the ore the stamp, however, also tends to convert it into slime. The hammer which cracks open the nut liberates the kernel without smashing it, but in pursuing the simile we find that the stamp not only breaks the shell, but both the kernel and the shell are further crushed, and their particles become confused together. The stamp which frees the gold from the quartz has to deal with a material in which the valuable and the valueless constituents are so uneven in size and so intermixed that the one is often crushed too much and the other too little.

I have seen auriferous quartz* which very nearly approached our simile of the nut. The gold occurred in seams and cavities in a quartz which had a honeycombed character. With such an ore there is just a certain blow which will break the brittle quartz and liberate the ductile gold. Such ideal conditions are very rare. The different parts of the same ore usually vary both in hardness and composition. The same work done on two pieces of mill-stuff will produce entirely dissimilar results. In the stamp-battery the heavy sulphide minerals are pulverized to a greater fineness than the siliceous gangue. When the gold is not too closely associated with the pyrite, coarse and rapid crushing will produce an adequate separation; but when the metal is in a finely divided condition and very

* At Clunes, Victoria, Australia.

intimately mixed with the pyrite, then fine crushing is demanded and can, unfortunately, only be obtained by the production of a very undesirable excess of slimes.

We have glanced at the results produced by the turn of the stamp upon the ore. Upon the mechanism itself the results are beneficial. The revolution of the stamp equalizes the wear upon the shoes and dies. It tends, also, by maintaining an even crushing-surface, to prevent that decrease of efficieney which occurs when either hammer or anvil has an irregular face.

Water is the vehicle used for the removal of the valueless portions of the ore from those which are valuable. Its low specific gravity as compared to both the metal and its enclosing gangue enables us to use it as a medium for their separation. A liquid having a specific gravity greater than that of water, and intermediate between that of the gold and its gangue, would be more effective if its use were practicable, which it is not.

In the mill, however, specific gravity is not the only factor we have to consider. The water discharged from a stamp-mill often transports the heavy pyrite further than the light quartz. This is due to the fact, already referred to, that the pyrite remains inside the mortar longer than the quartz and becomes pulverized to a further degree of fineness. It, therefore, presents a larger surface to the water. Again, the metallic sulphides commonly occurring in gold ores have a cleavage more highly developed than that of quartz; therefore, while the latter finds its way into the water in irregular and angular grains, the former will be found in thin plates and flakes, which readily float upon a running stream.

Water is the fluid used, but air also plays its part. During the time of its violent agitation under the falling stamp, the water entangles a certain amount of air. Such air exists in the form of small bubbles which hold the finely-pulverized ore in suspension and thus become the main agent in the floating of the slimes. Warmth causes the air to expand and the bubbles to become dissipated; therefore any rise in the temperature of the water, such, even, as is caused by the impact between the stamps and the ore upon the die, is favorable to a diminution in the amount of slime.

When the pulp is discharged from the mortar-box it runs down copper plates covering long sloping tables. The copper, whether plain or silver-plated, is provided with an amalgamated surface, and it is this amalgamated surface which is supposed to do the

work of arresting the gold. Mercury unites with gold forming a heavy amalgam; but, in practice, it is found that a plate which is covered with a good coating of gold-amalgam will serve to arrest gold much more effectually than a clean surface of either amalgamated silver or copper.

The amalgamating-tables have a slope varying with the amount of water used, the heaviness of the pulp, and the rapidity of the crushing. A gradient of $\frac{1}{8}$-inch per foot is common in Australia, while in Colorado the inclination is over 2 inches per foot.* The colonial mills consume 5 gallons of water per stamp per minute, while those of Colorado use less than 2 gallons. Theoretically, the use of the least possible quantity of water, and the spreading of the pulp over the largest possible surface, will give the best separation of the gold from the gangue. In practice, the varying composition of the ore prevents a nice adjustment of the conditions. You may readily determine an inclination which will be most effective in causing a separation of the gold from the quartz, but, it may be such as to cause the pyrite to settle. On the other hand, the slope may be so adjusted that the pyrite is carried away; but, such conditions may then be obtained as will also permit of the escape of the gold.

The amalgamating-tables are attached to the frame-work of the mill. The vibration set up by the falling stamps causes a pulsation of the water flowing over the plates similar, in a way, to the action of a jig. This assists the work of gravitation. The vibration has, however, another effect, namely, that of crystallizing the iron of the working parts of the mill, making them brittle and decreasing their time of service. In this, as in other respects, the stamp-mill presents contradictory features.

At the outset, we described milling as the art of treating an ore so as to extract the maximum of value at the minimum of expense. Let us apply the description to the two types of mill to which particular reference has been made. In Colorado, a stamp crushes 1 ton of the ore of the Gilpin county mines in 24 hours, and the cost, using free water power, is 70 cents. In California, the best equipped large mills crush at the rate of rather more than $2\frac{1}{2}$ tons at a cost, also using free water power, of about 35 cents per ton. The extraction in both regions will be, by amalgamation alone, about 70 per cent. We will omit the amount extracted by the concentration of any valuable pyrite, because the percentage of such material is

* An Australian mill usually crushes 2 tons per stamp per 24 hours.

very variable, and it forms a by-product, the value of which depends largely upon local conditions.

The ore of the Gilpin county mines carries about 15 per cent. of pyrite, and other heavy sulphides. The gangue is more feldspathic than quartzose, and is the product of the alteration of the country-rock—granitoid gneiss—and of the dikes* which penetrate it. The gold is not only present in a state of very fine subdivision, but it is also intimately associated with the pyrite.

On the other hand, the mill-stuff treated in Amador, Calaveras and Tuolumne carries from 1 to 2 per cent. of pyrite. The gangue is quartz, but the ore also contains a very large proportion of the country-rock, which in this case is slate, augite schist, and diabase. Of these, slate predominates. The gold is coarser than that of the Colorado ore, and it is not so closely associated with the pyrite.

Let us now consider the results to be obtained by an interchange of treatment, using California batteries on Colorado ore, and *vice versa*.† The Gilpin county ore is of medium grade, say 8 dwts., or $8 per ton. The local methods extract $5.60‡ at a cost of 70 cents. A California mill would give an extraction of only $4, but would crush such soft ore fully three times as fast, so that the cost would be, say 25 cents, giving a net yield of $3.75 as against $4.90 obtained by the methods of the district. Here, the slower mill gives the best results with a particular ore, and the Colorado millman considers the Californian very stupid because he does not use Colorado methods. Let us go to California and use the Gilpin county mill upon an ore of simpler character and of lower tenor. We will consider the treatment of an ore containing 6 dwts., or worth $6 per ton. The California mill would extract 70 per cent. at a cost of 35 cents, leaving a balance of $3.95 per ton. The Colorado battery would extract an increased percentage, say 75 per cent., but the ore being much harder than that of Gilpin county, the crushing capacity would be less and the cost per ton greater than when treating Gilpin county ore, say, therefore, $1.00 per ton, leaving a net yield of $3.50 per ton. The California mill, if crushing 100 tons of ore per day, would, therefore, show a profit $45 per day greater than that of the Colorado mill. As a matter of fact, there are other practical considerations which would render inadvisable the interchange of

* The "porphyry" of the miners; really, quartz-andesite.

† In making the comparison the cost of motive power, being very variable, is left out of the count.

‡ Amalgamation only, omitting concentration afterward, is here included.

methods, among which may be mentioned the smaller size of the ore-bodies of Gilpin as compared to those of California; while it must also be remembered that the construction of a Colorado mill of a capacity equal to that of a California plant would require twice as much capital.

The comparison just made will serve as an illustration of the fact that milling is a business for getting money, and not a scientific pursuit directed to the obtaining of a perfect metallurgical treatment.

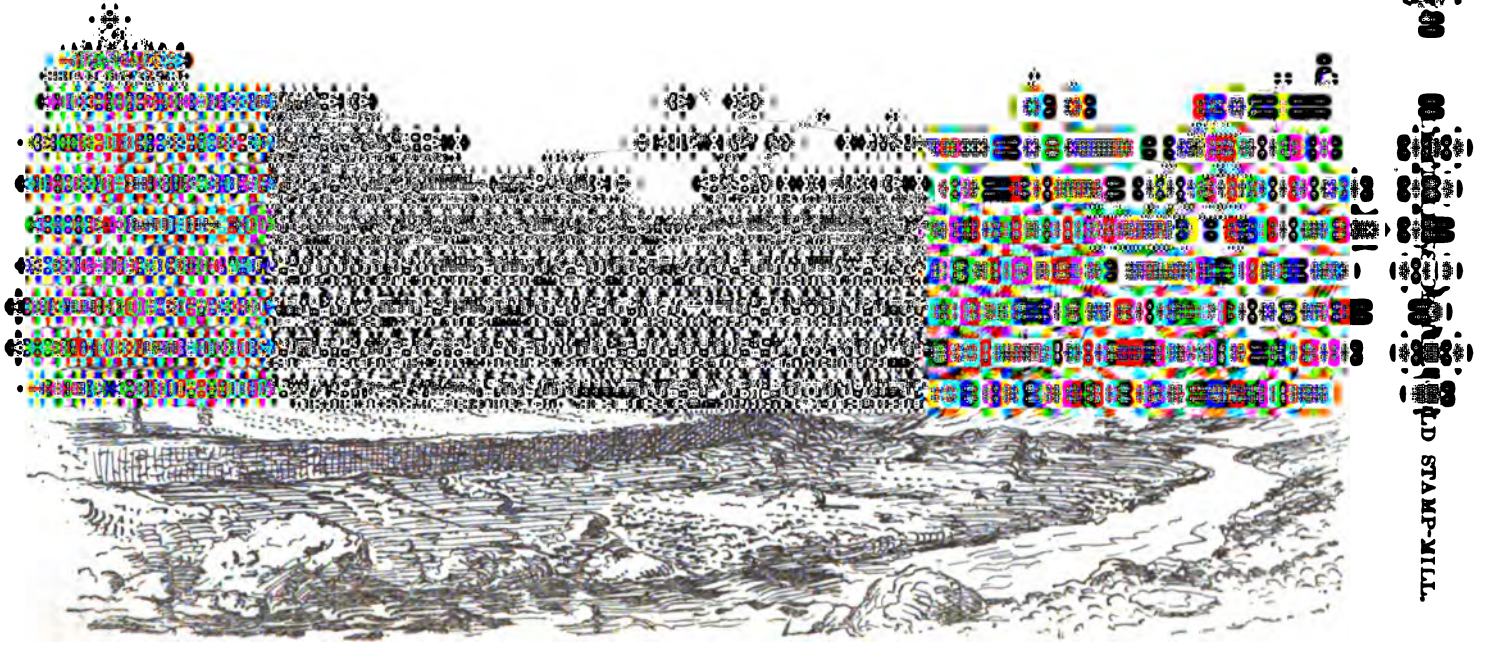
The contrast between the methods in use in two mining districts in the same country, illustrates the first axiom of all successful ore-reduction, namely, that the treatment must be suited to the character of the ore. Colorado methods in California would probably fail just as surely as California ways have been unsuccessful in Gilpin county. This is a truism not always remembered by machinery firms, who do not desire to be bothered by the making of new patterns. Too often, the ore is required to bend to a certain treatment in a mill of a particular design, instead of the mill being modified to suit the necessities of a particular ore.

The stamp-mill has presented to us many contradictory features. It is seen to be compounded of good and ill. It may be simple, but it is clumsy; it may be crude, but it is effective. As a machine, it has undergone an evolution common to all human inventions. It was founded on the first stone implement of the prehistoric savage; it became modified into the *matate* of the Mexican and the tilt-hammer* of the Chinese; it progressed until running water was called in to aid human muscle, and in the machine of the Hungarian peasant, it reached the primitive type from which our present mills were evolved. How great has been the comparatively recent improvement can be seen by stepping from Hungary to California.

In the valleys around Verespatak, in Transylvania, the larger mills† consist of twelve stamps, in coffers holding four each. The power is derived from an overshot water-wheel 10 feet in diameter. The cam-shaft is of iron, and revolves on agate bearings, lubricated with water. The lifter, or cam, is iron-shod. The stamp weighs 250 pounds, and has an agate head. The stem, the coffer, and all

* "A Chinese System of Gold-Milling," by Henry Louis, *Trans.*, xx., 324.

† Modern American mills have been lately introduced, and can be seen working side by side with those dating back to 100 A.D. For the particulars above given, I am indebted to Mr. E. H. Liveing.



The Old and the New.

the rest, are made of beechwood. Each stamp drops 30 times per minute, and crushes about 300 pounds of soft ore per 24 hours. These machines have changed but little since the time of the Roman occupation under Trajan, when this district was a part of the province of Dacia.*

Let us now go to California, whose record is little more than the record of a generation. Among the foothills of the Sierra Nevada we find mills containing 80 stamps, weighing 750 to 850 pounds each, and dropping 95 times per minute. Those of the working parts which are not of iron are made of steel. At single mills, 200 tons of ore are crushed per day. The mill building has a height of 70 feet, and the ore is never touched by manual labor from the moment that it arrives at the top in the mine-cars to the time when the waste is discharged at the bottom.

In Transylvania, the individual shareholder often has his own mill; in California a thousand unite to operate one, which can, in 24 hours, treat as much ore as the Hungarian mill crushes in 100 days. The little machine of the Hungarian has been tapping away like a woodpecker for eighteen centuries, and yet has not produced as much gold as has been contributed in the brief time of one generation by that completer mechanism whose muffled thunder echoes among the cañons of California.†

What has been done may serve as a measure of what can yet be done. Perfection is as unattainable in milling as in any other branch of industrial art; otherwise progress were soon ended. We can compare the old mill with the new, not only with a complacent satisfaction at the advance that has been made, but with the consciousness that where so much improvement was possible much room for improvement must remain.

It is not for me to attempt to foretell what place the stamp-mill is destined to hold in the metallurgy of the future. Let me, however, in concluding, suggest the reflection that though the appliances of to-day may show a great advance upon the older more imperfect type from which they were evolved, yet there is no mining district that possesses a mill which cannot, in some essential, be improved upon.

* Well-preserved gold coins of the time of Trajan have been found in the mine-dumps.

† The accompanying illustration of an old and a new mill has been engraved from a pen-and-ink drawing, made by my friend, Mr. H. R. Pridham, after a photograph taken by myself during my residence in California, some years ago. In the middle distance is an old ruined water-wheel, formerly the motor of a small ten-stamp mill, the dismantled portions of which remain in the shed on the left. In the background is a fully equipped, modern, California steam-mill.

IRON ALLOYS WITH SPECIAL REFERENCE TO MANGANESE STEEL.

BY R. A. HADFIELD, SHEFFIELD, ENGLAND.

(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

I.—IRON.

PROFESSOR ARNOLD, of the Sheffield Technical School, who has done so much excellent work in metallurgical research, recently produced, with the aid of aluminum, a sound ingot and bar from the purest known Swedish brand containing 99.8 per cent. of pure iron. Table I. shows the physical quantities of this metal.

TABLE I.—*Tests of a Sample of Almost Pure Iron Prepared by Professor Arnold from D. V. Swedish Bar, Containing Before Fusion* 0.04 *Per Cent. of Carbon.*

	I.*	II.†	III.‡
Series mark,	136	1.371F	.....
Analysis, per cent., C,	0.07	0.07	.....
Si,	0.04	0.04	.....
S,	0.02	0.03	.....
P,	0.02	0.015	.....
Mn,	0.06	0.07	.....
Al,	0.03	.....	.....
Fe,	99.76	99.81	.....
Specific gravity,	.....	7.863	.....
Original diameter, inches,	0.564	0.798	0.798
Original area, square inches,	0.25	0.50	0.50
Limit of elasticity, tons per square inch,	.....	18.	3.§
Breaking-load, tons per square inch,	21.	23.	14.75
Total elongation, per cent., measured on 2 in.,	50.	49.25	61.
Total reduction of area, per cent.,	80.	69.60	61.20
Extension at permanent set, per cent.,	.....	0.007	.....
Appearance of fracture,	silky.	silky	silky and granular in parts.

* I. Tests of Professor Arnold.

† II. Tests from the same bar of steel by Hadfield.

‡ III. Sample of pure copper tested by Hadfield for comparison.

§ Probably; not measured exactly.

The tenacity of pure iron (though so far commercially no absolutely carbonless iron has yet been obtained, Professor Arnold's sample containing .07 per cent. C.) is about 18 to 21 tons per square inch; but by admixture of various elements, and by judicious hardening and tempering, or treatment of similar nature, this property can be increased in forged bars up to 110 tons, or in wire to over 200 tons per square inch. Its yield or permanent set may be as low as 6 or 8 tons per square inch, or as high as 50 or even 60 tons per square inch, when in the form of bars. Its ductility, when tested on a length of 8 inches, will reach a maximum of 30 to 35 per cent. in the case of mild carbon steel, or even 51 per cent. in the case of manganese-steel. Its reduction of area rises as high as 75 per cent. in very soft products.

There is much difficulty in giving a satisfactory explanation of the phenomena which are observed to attend the hardening of steel. Many theories have been put forward from time to time, and in the last few years the admirable researches of M. Osmond, in France, and Professor Roberts-Austen, in England, have led to great advances in the observation of the behavior of iron under thermal treatment, as well as of the molecular changes which attend the hardening of steel. The value of these particular researches cannot be easily over-rated.

The Beta-Iron Theory.—Claiming both these investigators as personal friends, it is with regret that the writer dissents from the hypothesis advanced by them with reference to a portion of their work. The law of atomic volume in its relation to steel alloys, so ably formulated by Roberts-Austen, will be undoubtedly of service to metallurgists; and Osmond's able interpretation of thermal changes will prove of far-reaching consequence; but that iron assumes a "Beta,"* or hard form, in the alloy known as carbon-steel, and also in manganese-steel, the writer believes is as yet unproved. Iron may undergo allotropic modifications, but at any rate this cannot be conscientiously accepted until more direct proof is forthcoming. Upon the suggestions put forward hitherto, it is difficult to believe that the profound molecular changes which occur upon quenching the comparatively soft metal steel are not directly

* In this paper *Beta*, or hard iron is meant to indicate a product such as occurs in an alloy or steel which by water-quenching at a suitable temperature has been rendered so hard that it will scratch glass, or form the edge of a tool or other cutting instrument.

dependent upon the carbon present, or that the latter only plays an indirect or secondary part, as the Beta-iron theory indicates.

M. Osmond in his paper on "The Critical Points of Iron and Steel," speaks of the Beta-iron theory as follows: "In opposition to the opinion generally accepted, I believe that it is not carbon but the allotropic Beta-iron which is the principal cause of these new properties," that is, the new properties communicated to the steel by hardening. (*Journal of the Iron and Steel Institute*, 1890, No. 1, p. 50.)

Professor Roberts-Austen, in the first report to the Alloys Research Committee, says: "Owing, indeed, to the temperature, the molecules of iron were only united loosely, and therefore it is true the red-hot mass as a whole was soft; but the individual molecules, if they could be readily got at, or could be resolved into their atoms, would be found to be hard."

It is difficult to suppose that two pieces of heated steel, one an ingot, too soft to become hardened by water-quenching, and the other tool-steel, hardening intensely at a low red heat, differ so profoundly as the terms just stated would indicate. In the practical manufacture of two such steels there is nothing to indicate differences so great.

As already remarked, Prof. Arnold has recently produced an almost pure iron containing, say, less than 0.10 per cent. carbon. In the behavior of such an alloy, as compared with that of hard carbon-steel when being forged, there is, up to certain well-defined temperatures, but little difference. That most significant change, the loss of magnetic properties by the iron, occurs in both at points not widely differing. The same remark applies to their electrical resistance. In fact, we have nowhere any proof, thus far, of such a change as would indicate that the 1-ton steel ingot which we are to-day forging into a shaft, and which we shall to-morrow machine and otherwise manipulate, is in its heated state composed of atoms or molecules which, if they could be extracted in that condition, would be found intensely hard.

Take another aspect of the case. The Beta hypothesis, if correct, must, of course, apply to pig-iron. Can it be maintained that in cast- or pig-iron of, say, three different grades, gray, mottled, and white, the differences can be referred to the indirect action of the carbon upon the iron rather than to its direct action, viz., the direct combination of the carbon with the iron as carbide of iron, so fully proven in Dr. Sorby's microscopic researches, and in the recent report of Prof. Ledebur on the particular forms of carbon in steel?

If we have no such combination, gray pig-iron is obtained, all or nearly all the carbon present being mechanically distributed as graphite. • Iron of this grade is also modified by the presence of silicon, an element which we know positively does not produce hardness in carbonless silicon-steel. In other words, silicon, up to certain considerable percentages, produces little or no effect in carbonless iron. But in cast-iron the silicon modifies the effect of the carbon, changing it into the graphitic or the combined form, according to the amount present. In such cases, be it noted, silicon acts not upon the iron but upon the carbon, and it is to the particular state in which the latter exists that softness or hardness is wholly due. Strange to say, the percentage of silicon ($2\frac{1}{2}$ to 3 per cent.) that would cause a softening effect in cast-iron has little or no effect in steel. If there is little or no carbon present the steel remains soft when quenched. If the usual hardening percentages of carbon are present, water-quenching produces the usual intense hardness.

White cast-iron, in which all the carbon is combined, is so hard as to serve, when cast in suitable shapes, as the material of cutting-tools. But if we chill strong gray iron of certain qualities quickly, we find that in that portion of the sample which has parted most rapidly with its heat, the carbon is in the combined form, whereas the portion which cooled more slowly still shows the mechanically diffused graphite.

In the different grades of cast-iron there is no progressive increase of carbon to complicate our deductions. The total percentage of this element may be constant in each of the three grades, and the resultant differences are entirely dependent upon the particular form which the carbon assumes, a form which may itself again be modified by differences in the rate of cooling, as in steel. No theory of hard iron seems requisite to explain these results. Probably the change noticed in cast-iron (apparently not so complex as that of steel or steel alloys) is an index to us as to the direction in which we must look for eventual explanation of the results obtained in hardening steel.

The Beta hypothesis will be further considered in the sections dealing with carbon- and manganese-steel. Some recent experiments with the latter by the writer may, however, be mentioned here, as they have considerable bearing upon this Beta-iron theory, and the results are, he believes, unfavorable to it.

A bar of manganese-steel was endowed with the curious property of being magnetic in one-half and non-magnetic in the other half.

It was originally non-magnetic throughout, and became magnetic by continued heating for a long period; and the part which is now non-magnetic was again brought to this latter state by being heated for a few seconds to a high heat, forged and water-quenched. These experiments are detailed more fully in the section relating to manganese-steel, but the facts are mentioned here as they seem to have an important bearing upon the Beta-iron question. It was suggested three or four years ago that the probable explanation of manganese-steel being non-magnetic was that the manganese held the supposititious Beta-iron in the non-magnetic state, a state which is known to exist when a certain temperature (about 750° C.) is exceeded.

It seems quite possible to imagine that iron, without actually changing its form, may, when in combination with carbon (the only element which has been found to confer this property of true hardening upon iron), assume such a structure or form of crystallization as to undergo the modifications which are met with in hardened carbon-steel. The microscopic researches of Dr. Sorby, one of Sheffield's most respected citizens, as well as later ones by Prof. Arnold, of the same city, indicate this latter direction to be the true one in which to look for a satisfactory explanation. The very fact that rapidity of crystallization is an essential to produce hardness seems an indirect proof that it will be by this branch of research—microscopy—that we shall next get more light.

Effect of Carbon.—Self-hardening steels, such as those obtained by alloys of iron with chromium and tungsten, still require the simultaneous presence of carbon. Such elements act as aids to hardening, but even self-hardening steels do not surpass, if they equal, the hardness of water-quenched carbon-steels, such as the pure Sheffield crucible-steels. Even the brittle 4 per cent. manganese-steel fully described in the writer's different papers becomes comparatively soft in its forged state and if cooled slowly enough. This latter material, containing about 0.35 to 0.40 per cent. of carbon is the only one among numerous steel alloys produced by the writer which has shown indications of approaching the ordinary high-carbon steel in its water-quenched hardness.* As shown in Prof. Roberts-Austen's excellent work on *Metallurgy*, even 0.3 per cent. of carbon must not be treated in any way as a negligible quantity. No one has shown more clearly than Prof. Roberts-Austen how powerful may be the effect

* The character of this hardness is, moreover, not like that of carefully hardened carbon-steel, but resembles that of overheated (often termed, incorrectly, "burnt") carbon-steel. The material crumbles easily, and is lacking in cohesion.

of small quantities of a second element upon the main constituent metal of an alloy. Such a percentage may have considerable influence in producing hardness, for we know that in the presence of manganese, carbon readily assumes the hard or combined form as a carbide of iron.*

The writer suggested some years ago the probability of manganese being a metal resembling nickel and chromium. Since that time there has been further evidence to show that it is a metal of different characteristics from those stated by the text-books, and probably not of that extremely hard nature usually imagined, just as chromium, before thought to be a hard metal, has now been clearly proved by Placet's specimens, electrolytically produced, to have quite a different nature. The samples given to the writer by M. Placet show a comparatively soft metal. Hitherto, investigations regarding the physical properties of manganese have been very imperfect. The writer has never been able to obtain a sample of this element in its pure state; but by the work of two American investigators, Messrs. Wahl and Greene,† it is hoped that before long carbonless and metallic manganese will be available. The studies of the properties of manganese will almost certainly throw much light indirectly upon this important question of the hardening of steel.

Second Form of Iron Not Proved.—As regards the bearing of allotropy upon this question, certainly no definite proof has yet been given that iron has more than one form. Recent research at the Sheffield Technical School has all gone to prove the facts noticed by the writer in his numerous alloy-experiments, that true hardness, which may be roughly termed "glass-scratching" hardness, is conferred by carbon alone. The one partial exception is the 4 per cent. manganese-steel; but this also contains 0.3 to 0.4 per cent. of carbon, and for other reasons before stated, it does not seem to constitute an exception which can yet be brought forward to upset the theory of "president" carbon. As the result of some recent experiments the writer hopes before long to produce a carbonless manganese-steel alloy, so that this important point may be definitely decided.

Allotropy.—The case of sulphur has been named as strongly supporting the probability of allotropic modifications in such a metal as iron. It should, however, be clearly borne in mind that, so far as

* See Mr. Howe's note on Mukai's Studies of Manganese-Steel, *Trans.*, xxi., 625.

† *Trans.* xxi., 887.

our metallurgical knowledge goes, the material called soft or wrought-iron has always the same qualities, unless modified by the presence of a second element such as the metalloid carbon or by some of the metals such as chromium, manganese and nickel; the former metal producing "glass-scratching" hardness, and the latter metals but little change when present in small quantities, and only stiffness when in large percentages.

Again, surely the allotropic change that occurs in the element sulphur is not of the same nature and cannot be compared with the extraordinary change of physical properties of carbide of iron in the form of steel. In the case of sulphur, the changes are temporary and unstable, and the differences in physical properties are trivial as compared with those which occur when carbon-steel is hardened. A comparison with cases of this kind can hardly be taken seriously when we think of the profound differences existing between pure iron with its tenacity of some 18 to 21 tons per square inch, and a carbon-steel which has been hardened and tempered, possessing a tenacity of 150 tons, or (in the case of the best quality of pianoforte-wire) over 200 tons per square inch.

In some other elements forming allotropic modifications the changes seem to be likewise very unstable and uncertain. As Prof. Tilden says in his excellent *Introduction to Chemical Philosophy*, speaking of the allotropes or isomerides, and changes in structure of bodies: "One form is generally less stable than the other, and sooner or later, especially under the influence of change of temperature, is converted into the permanent variety."

In many instances the more rare allotropic forms as compared with those better known are unstable. Tin is often quoted as a metal subject to allotropic changes. The gray, brittle form has a specific gravity of 5.8. By heat or pressure it passes into the white or malleable form of 7.3 specific gravity. This again, by considerable reduction of temperature, reverts to the brittle species, as pointed out by Prof. Roberts-Austen, with regard to the behavior of the buttons on the overcoats of certain Russian soldiers. Sulphur is more unstable even than tin. True, if cooled suddenly from a temperature of 240° or 250°, the product is a tough, elastic material, quite different in aspect from ordinary sulphur, and also insoluble in carbon bisulphide. But, as pointed out by Prof. Tilden, this form, "after being kept a few hours, becomes brittle and crystalline, and recovers its solubility in the usual solvents."

That the importance of allotropy may be overestimated has been

recently shown by Dr. Alder Wright, who, in his research on alloys of aluminum and antimony, found that certain of these alloys disintegrated spontaneously on exposure to air, and that the loss of coherence was not due to the assumption by the alloy of some allotropic form, but was merely the effect of oxidation.

No such unstable properties characterize steel in its hardened as compared with its unhardened state. The former has pronounced characteristics of a different and permanent kind. Does not this indicate that, even if allotropic changes occur, they are not such as to warrant the belief that the soft metal iron, *per se*, has become entirely revolutionized in its condition and properties.

In stable allotropic transformations, the change in physical properties is usually very profound and decisive. If, therefore, Beta-iron were proved to exist, it is difficult to imagine that there could be partial or varying degrees of allotropic modification, such as exist in the same steel quenched at varying temperatures. It does not seem possible to admit the explanation that there may be varying proportions of both Alpha- and Beta-iron in the same specimen. The very theory which indicates where the change to Beta or hard iron is supposed to occur (marked by an arrest in the rate of cooling, and by an equally revolutionary loss of magnetic properties) must of necessity apply to the whole mass; for the whole mass becomes non-magnetic. But, as a matter of common knowledge, the value of carbon tool-steel is due not merely to its property of becoming hard when water-quenched, but also to the fact that by tempering—not to be confounded with the French "trempe"—almost imperceptible gradations of hardness can be obtained. Some day, when expert manual work is rated at a higher value than now, it will be discovered that the workman to whose care is intrusted the hardening and tempering of the innumerable articles made from steel, should be dealt with as an artist of no mean degree—an artist, who, when he has received an education of somewhat higher standard than at present, will have to be more generously recompensed. The writer has known cases in which a skilful artisan has been able to detect by difference in the behavior of steel under hardening and tempering as little as 0.05 to 0.10 per cent. variation in the carbon. Mr. Metcalf,* too, has pointed out in his interesting book on the treatment of steel that a trained expert can sort by means of the

* No one has done more than Mr. William Metcalf, of Pittsburgh, to show the delicate and accurate treatment to which tool-steel of good quality should be subected to secure the best results.

eye different brands of carbon-steel ingots, varying as little as the above in their percentage of carbon.

II.—Carbon.

Carbon and Iron.—This is so far the only metalloid which has been proved to confer "water-hardening" qualities upon iron. From the marvelous character of the stonework and masonry brought to light by recent Egyptologists, it would seem almost certain that steel tools must have been used for producing this work. If this be so, the use of carbon-steel must date back at least 4000 years. The writer has recently read the fascinating book of Mr. S. Lang on *Human Origins*, but cannot agree with his conclusions that such work executed at least 3000 to 4000 years ago, in then civilized Egypt and Assyria, was effected with copper or bronze tools. It does not seem possible that any method of producing hard bronzes would give a material for tools capable of chipping and facing granite or other hard stones.

It is believed that the three oldest pieces of "wrought-iron" in existence—whether these are carbon-steel or not the writer has not yet been able to ascertain—are a sickle-blade, found by Belzoni, under the base of a sphinx in Karnak, near Thebes; a blade found by Colonel Vyse embedded in the mortar of one of the Pyramids, and a portion of a cross-cut saw exhumed by Layard at Nimroud. All these are in the British Museum.

An interesting account was recently published of the tunnel driven from the so-called Spring of the Virgin, near Jerusalem, to the Pool of Siloam. A tablet at the mouth of the tunnel contains what is held to be the oldest example of Hebrew writing, possibly dating from the time of Solomon. The translation reads: "Behold the examination. Now this is the story of the tunnel. Whilst the miners were still lifting up the pick toward each other, the voice of one called to his neighbor, so they heard each other, and the miners struck each of them the other pick to pick." The tunnel was driven from each end in solid rock to a total length of about 1708 feet. This is referred to because one can hardly imagine this work being accomplished with any other than carbon-steel tools.

Carbon in Cast-Iron.—The behavior of carbon in cast- or pig-iron seems much more easy of explanation than in steel, where its action is very complex. For example, a cast-iron, otherwise of pure quality, containing 2½ per cent. of silicon, and therefore very gray, can hardly be chilled, and in most cases only slightly, even if cooled

most rapidly. Yet the writer has, with a 2½ per cent. silicon-steel, containing at the same time about 0.8 per cent. of carbon, made tools the hardness of which when water-quenched was sufficient to turn chilled rolls with ease, this being an exceedingly severe test. One would have expected that silicon in this instance would have acted as in pig-iron, or even that where the carbon was less, the influence of silicon would have been more powerful. Yet the opposite effect takes place.

The hardness and softness of ordinary grades of cast-iron seem clearly dependent upon the particular form of carbon present. So far two forms are well known, the graphitic and combined, though the latter requires classifying into further forms, now so clearly proved by Ledebur to exist. It is true that in "chilling" cast-iron, as in steel, we do not know why a soft metal like iron is converted by the presence of carbon into an extremely hard product. But in cast-iron it has always seemed, at first sight, easier to understand than in steel, because graphite, with which we do not associate the characteristics of hardness, is always present in soft iron, whereas this partly disappears in mottled, and entirely in hard white cast-iron. There has not been so much difficulty in understanding why the diffusion of graphite, etc., through a mass of iron does not confer hardness. When, however, we ask why that form usually designated as "combined carbon" does so, we meet the same difficulty as in studying the hardening of steel. Finally, this brings us to the conclusion, in itself of no little value, that the same causes which produce hardness in steel also do so in cast-iron.

Abel's Investigations.—The recent president of the Iron and Steel Institute, Sir F. Abel, did perhaps more than any other investigator to call attention to this question. In 1881 he presented his first report to the Mechanical Engineers' Committee on the Hardening of Steel, and again in 1883, his "Report on Further Experiments Bearing upon the Question of the Condition in which Carbon Exists in Steel."

These reports proved that in steel gradually cooled, the carbon exists entirely, or nearly so, in the form of a definite iron compound, rich in carbon, which is disseminated through the mass, having been eliminated from the iron, during the process of cooling, in a more or less distinctly crystalline form; that the carbide is again assimilated by the metal when it is raised to a very high temperature; and that if a metal be suddenly cooled there is no time for the elimination to take place, and the carbon or carbide remains dissolved in the metal

more or less completely, according to the degree of rapidity with which the cooling process is carried out.

In his second report, he says: "Further experiments confirmed the correctness of the view that the carbon present in the cold-rolled samples of steel examined, existed not as simply diffused mechanically through the mass of the steel, but in the form of an iron carbide—a definite product, capable of resisting the oxidizing effect of an agent which exerts a rapid solvent action upon the iron through which this carbide is distributed."

Ledebur's Investigations.—Prof. A. Ledebur, of Freiberg, has still further elucidated this important question in the papers submitted by him to *Stahl und Eisen* on the "Nomenclature of the Various Forms of Carbon in Iron" (vol. viii., November, 1888) and "Recent Experiments on Carbon in Iron" (vol. xi., April, 1891), and still later by his treatise presented to the Berlin Institute for the Promotion of Technical Industries, for which he has received their special award.

TABLE II.—*Cast-Steel not Forged.*

	SPECIMEN A.		SPECIMEN B.	
	Before Annealing.	After Annealing.	Before Annealing.	After Annealing.
Hardening carbon	.14	.08	.36	.16
Carbide carbon	.44	.52	.62	.92
Graphite and temper-carbon	.00	.01	.00	.01
Total carbon	.58	.61	.98	1.09
Silicon	.23	.....	.28	.....
Manganese	.18	.....	.20	.....

TOOL-STEEL.

	As Forged.	Hardened.	Hardened and Tempered at blue heat.
Hardening carbon	.22	.65	.36
Carbide carbon	.71	.38	.67
Graphite- and temper-carbon	.00	.00	.00
Total carbon	.93	1.03	1.03
Silicon	.11	.....	.....
Manganese	.11	.....	.....

He has clearly proved that what is known as combined carbon is made up of two entirely distinct forms of carbon, which, according to the proportions of each, affect the properties of iron in a widely different manner. Hardening-carbon, alloyed with the main substance of the iron, has exceedingly powerful properties.

Ledebur gives a considerable number of examples, and his analyses of steel show, instead of merely "carbon," three headings: 1. Hardening Carbon. 2. Carbide Carbon. 3. Graphite- and temper-Carbon. These are shown in Table II.

These analyses throw much light on the changes in the form of carbon which occur in the thermal treatment of steel. They show how much is wanting in our present methods of commercial analysis. With the increasingly severe tests stipulated by the mechanical engineer, more attention will have to be paid to the different states or forms assumed by carbon in steel.

III.—Manganese-Steel.

Next to carbon, manganese has been found the most useful of elements in the manufacture of steel and its alloys. Heath (about 1840) was probably the first to recognize its importance fully. He applied the black oxide to the manufacture of crucible cast-steel. Robert Mushet followed, employing manganese-alloys on a still wider scale to cheapen the manufacture of crucible and Bessemer steel. Henderson was the first to produce for commercial use the rich ferro-manganese now so important to steel-makers, and this line was followed up by Prieger. The Terre Noire Company improved upon these earlier processes, and it is to this company, whose exhibits at Paris in 1878 were a marvel in the combination of technical and scientific skill, that we owe the first production of a rich and cheap ferro-manganese. Without this product it would not have been possible to manufacture the excellent soft steels produced in such enormous quantities during the last ten years.

The Terre Noire Company, at the exhibition referred to, showed an interesting set of steel samples containing up to about 2½ per cent. of manganese. But at this point, owing to the brittleness of the product, whether cast or forged, their experiments stopped. Naturally enough they imagined that further additions would only produce still more harmful effects.

At the Hecla Works, Sheffield, however, owing to peculiar and unexpected results which had been obtained with other steel alloys, systematic experiments were carried on, which resulted in the dis-

covery of what is now known as manganese-steel. It was found, as metallurgists are well aware, that startling changes were obtained by the addition of varying percentages of manganese, many of them being quite surprising. A description of this material naturally falls under two heads, covering respectively its unhammered cast state and its forged state.

Cast Manganese-Steel.—Ordinary steel, whether cast or forged, may contain as high as 1.25 per cent. of manganese without showing any marked change in quality, provided the carbon is low. The writer has seen many excellent specimens of steel castings, containing as much as this percentage, giving good results, both under the drop-test and in the testing-machine. But after this is passed, a decrease in strength and ductility occurs, and this is accentuated in a remarkable manner at a point somewhere between 3.5 and 5 per cent., when an exceedingly hard and brittle cast material results. The writer has pounded into fine powder, with a small hand-hammer, thin sections of such steel, yet the same material is as ductile and malleable when hot as mild steel. This extreme brittleness is obtained when the steel has been cast very hot into thin sections or small ingots 2.5 to 4 inches square, and is partly caused by the peculiar crystallization accentuated by the thin sections or forms into which the steel is run.

The brittleness is not so marked if the metal is poured at lower temperatures; but no matter in what form or shape steel containing from 3.5 to 6.5 per cent. of manganese is cast, it is always considerably deficient in strength as compared with ordinary cast-steel. Beyond about 6.5 per cent., a remarkable change occurs. The exact point where the brittle nature of the material alters is influenced by the casting temperature and other considerations, and cannot be precisely stated; but toughness and ductility gradually return. There is probably no sharply defined point, but a merging effect similar to that obtained in carbon-steel. Beyond 6.5 or 7 per cent. there is not only a remarkable increase of strength and ductility, but also a change in many of the physical qualities. The alloy becomes less and less subject to magnetizing forces; and at 13 per cent. it is practically non-magnetic under the strongest influence. As Dr. Hopkinson says:

"The magnetic property of iron is annihilated, and the comparatively small quantity of manganese present enters into that which must be regarded for magnetic purposes as the molecule of iron, and completely changes its properties. The fact is one which must have

great significance in any theory as to what is the molecular nature of magnetization."

Several years' experience in the manufacture of cast manganese-steel have led the writer to believe that a special explanation of its qualities of toughness and resistance to fracture by concussion is needed. It has been commonly imagined that what is known as the toughened material is secured in the casting without further treatment. This is not wholly true. Although sometimes the material even in its cast state is remarkably tenacious and ductile, notwithstanding its hardness, a further treatment, such as water-quenching, gives the best results. The material as cast is often tough, especially if cast in iron moulds, but it is to some extent uncertain. The writer is inclined to believe that the variation noticed in its properties is somewhat dependent upon the casting temperature and other similar causes, some of which are not yet fully understood. In all cases, however, there is a remarkable difference between the strength of the 10 or 12 per cent. as compared with that of the 5 per cent. manganese-steel. The former, even if not very tough when cast, is always improved by water-toughening, whereas the latter, no matter what may be the treatment, is entirely lacking in strength, and although useful for some purposes would usually be, by itself alone, of little service. It is at about 14 per cent. that the maximum of strength is obtained. After that point a decrease occurs; but the true cause of this is made complex by the higher percentage of carbon in the material, necessarily resulting from the high carbon even of the richest ferro-manganese. From results of special experiments carried out by the writer with manganese-steel containing less carbon than that usually found, it appears quite possible that if the carbon could be reduced, there would be considerable strength in the material containing 25 or even 30 per cent. manganese. At present, however, there seems to be no special gain in a reduction of carbon, since the latter element is to some extent an advantage, as will be seen from the details given later in this paper.

The above statements relate entirely to the properties of cast manganese-steel, which it must be remembered, differ in several ways from those of forged manganese-steel. The writer has not been able to ascertain the exact tenacity and ductility of cast manganese-steel. It has not been practicable to obtain satisfactory sets of cast test-bars, owing to the difficulty of preparing the specimens and the uncertain manner in which they behave in the testing-machine. Tensile tests do not seem to indicate the qualities of this cast material, as will be seen from experiments detailed below.

In any case, however, the tenacity is low, not exceeding 32 to 34 tons per square inch, even with the toughest and hardest description of cast manganese-steel. A cast-bar which will bend double cold and require much greater force to produce this doubling up, shows only about the same tenacity as a mild cast carbon-steel bar which can also be bent double cold, but with at least 30 or 40 per cent. less pressure.

Forged Manganese-Steel.—The exact qualities of this can be accurately determined, as test-bars can be forged carefully to shape and up to 22 per cent. The writer has so fully detailed his tests in the papers presented to the Institution of Civil Engineers and the Iron and Steel Institute that it seems unnecessary to give more than a selection from the latest tests, showing the effects of the usual percentages of manganese in this steel.

The same general statements as to the effects produced by increased percentages of manganese apply to the forged as to the cast material. The point where the greatest brittleness occurs is about 5 per cent. Heating or quenching treatment does not seem to modify this to any extent; and it is difficult to conceive that the same element, manganese, when doubled or trebled in percentage, can really produce such entirely opposite effects. With 10 per cent. of manganese the water-toughened material possesses about as much ductility as mild steel, though with much higher tenacity. Somewhat peculiar is the considerable difference which again occurs between a 10 per cent. and a 13 per cent. manganese-steel. In the latter there is a considerable increase both of tenacity and ductility. Nor can this be entirely ascribed to the increase of carbon necessarily accompanying the rise of manganese, for in two qualities (1.1 and 1.3 C) recently produced by the writer, between which there was little difference except the percentage of carbon, the respective tenacities were not very different.

For the same reason as was suggested with regard to cast manganese-steel containing 25 per cent. manganese or upward, it is probable that such products would be forgeable if the carbon were not so high. With about 22 per cent., malleability ceases. As was also observed concerning the cast material, there seems no particular object in manufacturing forged manganese-steel containing more than about 14 per cent. of manganese. So far as we know at present, there are no further special changes in the physical qualities of the material, or the changes are not of such a nature as to make them of special service in the arts.

Attention is drawn to the fact that there is no great increase in

tenacity by the increase of manganese unless accompanied by water-quenching. The reasons have been well discussed in an interesting paper on this question by Mr. Tetskichi Mukai, of Tokio, Japan.* It is water-quenching which gives the extraordinary tenacity and ductility noticed in the 13 per cent. specimens.

IV.—Uses of Manganese-Steel.

As is well known, the application of manganese-steel has been restricted by the difficulty of machining and getting it into finished shape. In a large number of articles for which it is now used, these difficulties have been surmounted by so arranging the castings or forgings that they can be put to use without any tooling. In this way the adoption of manganese-steel has proved advantageous in many cases, a higher first cost being compensated by the saving of the cost of machining.

Manganese-steel has the considerable advantage of being almost as free from blow-holes or honey-combs as cast-iron. In ordinary cast-steel castings, blow-holes are still an appreciable factor. That its fluidity is much greater than that of cast-steel, is shown by the fact that small wheels, weighing about 5 ounces each, are made of it, the arms of which are only $\frac{1}{16}$ inch thick.

Its contraction is very considerable, nearly $\frac{5}{8}$ inch per foot, thus increasing the difficulties of manufacture.

The first cost is necessarily much greater than that of ordinary steel, but with a growing demand this difficulty is also being gradually met.

Its hardness, although preventing the machining or fitting to exact shapes, has indirectly proved an economy, as already indicated, through the fact that articles made of it must be produced so as to avoid these expensive processes, except where grinding or special devices can be employed. For example, it is generally customary to turn ordinary steel dredger-pins so that they may very exactly fit the bushes of the links and bucket-backs. By skill in manipulating the manganese-steel pins, the writer's firm has now turned out many thousands forged very truly to size. These are found, for all practical purposes, to be equally efficient; the machining is saved, and a set-off is obtained to the increased first cost of this steel.

It is therefore better to arrange that articles of manganese-steel,

* The substance of this paper was communicated to the Institute by Mr. H. M. Howe, in his "Note on Manganese Steel," *Trans*, xxi., 625.

[illegible] TO MANGANESE STEEL.

Castings of Manganese Steel.

whether cast or forged, be so designed that they can be put to work in their unfitted condition. In the case of links, wheels, pulleys, gearing, etc., arrangements are made for casting into the articles soft steel or wrought-iron bushes or liners. The latter method, however, sometimes cannot be applied, owing to difficulties in the foundry.

Plates I. and II. show manganese-steel castings and forgings. In Plate II., the ingot (Fig. 1) in the center, weighing about 2 tons, was successfully forged to a slab 4 inches thick under one of the heavy steam-hammers of the Bethlehem Iron Company.

Figs. 2 and 3 are the tire and axle referred to in Tables XI. and XII. Figs. 4 and 5 represent 33-inch wheels of manganese-steel, now being tested in railroad service. Figs. 6 and 7 represent the rings being used for crushing hard silica and other fire-proof preparations, as also referred to in Table III., A.

Dredger-Pins.—One of the first successful employments of this steel on a large scale was for dredger-pins. Although ladder-dredgers are not so much employed in America, large numbers are at work in Great Britain and on the continent of Europe.

It will be readily understood that the moving parts of these machines are specially subject to great wear and tear. The writer has seen dredger-pins or bolts 4 inches in diameter, made of ordinary carbon-steel, which connect the links and bucket-backs so as to form one continuous chain, worn more than half-way through their section in eight or nine weeks. Manganese-steel pins have not worn more than $\frac{1}{8}$ inch in the same time.* The engineer of a large phosphate-mine in South Carolina reported, after a very careful trial, that manganese-steel would outwear not less than four pins of ordinary steel. The same remarks apply to the bushes used both in the bucket-backs and links. So successful has this application proved, that Hadfield's Steel Foundry Company, of Sheffield, England, has now sent out more than 12,500 pins and 8000 bushes of manganese-steel. Practical engineers, such as Mr. Leader Williams, of the Manchester Ship Canal; Mr. Charles L. Hunter, of the Bute Docks, Cardiff; Mr. R. Pawley, of the Hull and Barnsley railway, at the Hull docks; Messrs. Cochrane and Fowler, of the Preston Corporation Dredging Department; Mr. T. R. Salmond, of the Belfast Harbor Office; well-known contractors, such as Messrs. S. Pearson & Son, of London, in their Mexican drainage canal contract; different dredging-

* Fig. 1 in Plate III. shows an ordinary steel pin, as used by the Preston Corporation after three months' wear. Fig. 2, a manganese-steel pin after ten months' wear.

Manganese-Steel Castings and Forgings.

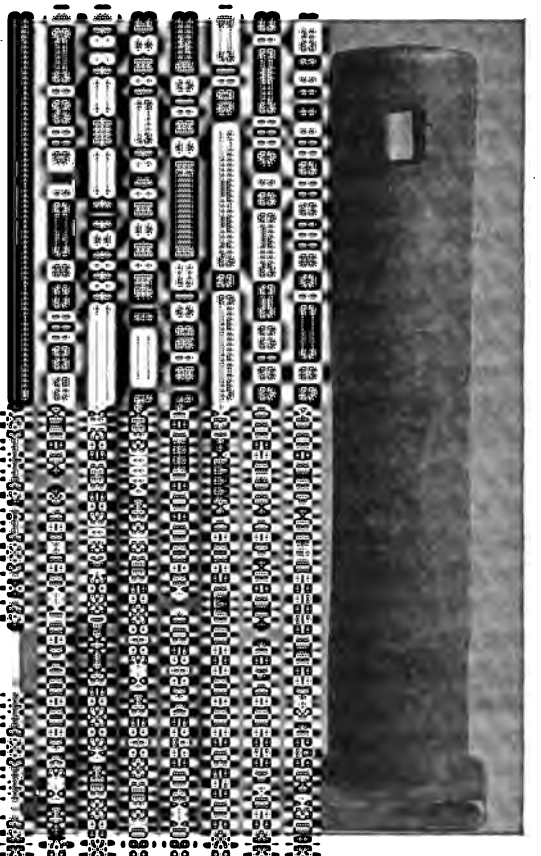
contractors in Holland, India, Australia, and Canada, along with other users, one and all, have spoken of the results obtained as most satisfactory. Full details are given in Table III.

TABLE III.—*Wear of Manganese-Steel Dredger-Pins.*

Name.	No. in use.	Material.	Time in use.	Official Report by the Engineer.
S. Pearson & Sons, London.	3850	Manganese-steel.	6 months.	"Scarcely perceptible."
Bute Docks, Cardiff; (Mr. C. L. Hunter, Engineer)	601	Manganese steel.	4 months.	"Little or no wear."
Hull & Barnsley Railway and Docks Co. (Mr. R. Pawley, Engineer) *	230	Manganese-steel.	7 weeks.	"No perceptible wear."
		Ordin'ry steel	7 weeks.	"Worn $\frac{1}{4}$."
		Manganese-steel.	19 weeks.	"Showed slight signs of wear."
		Do.	27 weeks.	"Worn $\frac{1}{4}$."
		Do.	77 weeks.	"Apparently would do a deal more work."
		Ordin'ry steel	10 weeks.	"After 10 weeks have to be repaired. This can be done three times, and the pieces are then put on the scrap-heap.
Preston Corporation—(Ribble Navigation.) (Messrs. Cochrane & Fowler, Engineers).	418	Manganese-steel.	8 months.	"Worn $\frac{1}{8}$ inch. Have worn out 4 sets ordinary steel pins, and to all appearances will outlast another 4 sets." These are shown in Plate III. by Fig. 2. Fig. 1 in same plate shows the wear of ordinary steel.
Belfast Harbor Commissioners. (Mr. T. R. Salmond, Engineer).	24	Manganese-steel.	8 months.	"Worn $\frac{1}{16}$."
		Ordin'ry steel	8 months.	"Worn $\frac{5}{8}$."
Manchester Ship Can'l. (Mr. C. J. Wills, Eng.)	1779	Manganese-steel.	4 months.	"Very little worn."
Phosphate Mining Co. South Carolina.	250	Manganese-steel.	.....	"Will last four times as long as ordinary steel."

* Mr. Pawley's series of very careful tests clearly shows that manganese-steel wore nearly three times as long as ordinary steel, to say nothing of the extra labor and expense incurred in repairing and replacing the latter. Thus it may be considered that the difference in favor of manganese-steel is at least 4 to 1, and this quite apart from the dredger's requiring no replacement of pins for such a long continuous period.

FIG. 2.



ordinary steel; Fig. 2, manganese-

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nganese-steel pins: "Curiously
ganese-steel pins are so much
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ent results detailed in Table
wley, indicate the value to the
a material possessing in its
enacity of 58 to 65 tons per
r cent. on 8 inches, and yet at
ingly high resistance to wear
inery of all classes require an

increasingly strong material in their construction. It is quite probable that when manganese-steel is better understood and has emerged from its infancy, it will be advantageously employed for many parts of millwright work, effecting both an increased efficiency and a saving in weight. This latter is, in many cases, of great importance. Although the high tenacity of this steel may not be the true measure of its value over mild cast-steel, it is difficult not to believe that eventually its application will be wide in general constructive work, seeing that a piece of manganese-steel whose final elongation will be from 40 to 45 per cent. on 8 inches, has only become permanently stretched .02 inch, while a bar of mild steel with the same stress has elongated 2.24 inches and has broken.

In addition to pins and bushes, manganese-steel tumblers, saddles, whelps, links, tines, bucket-teeth, etc., have been made with satisfactory results.

A large tumbler weighing nearly two tons, cast in such a manner that it could without machining be keyed on to a shaft of ordinary steel, has given excellent wear. After twenty-one months' use it showed a wear of 6.9 square inches on line of section (Fig. 2, Plate IV.). The ordinary cast-steel showed 29.5 square inches (Fig. 3).

Crushing- and Grinding-Machinery.—Although in some special cases the results have not been so good as expected, yet in the main the wear of manganese-steel has proved as remarkable here as in its application to dredger-work.

This material has a curious combination of qualities; it is so hard that practically it cannot be machined, and to drill through a thickness of $\frac{1}{2}$ inch would spoil the best drill, yet in its *cast* state it has an internal looseness of texture. This is brought out in the tensile tests that have been made; the tenacity seldom exceeds 30 tons per square inch, though in the forged and toughened state this is doubled.

Again, in compression, as shown in the writer's paper before the Institution of Civil Engineers, there is a shortening of from 15 to 20 per cent. by a load of 100 tons per square inch on a specimen 1 inch high and 0.79 inch in diameter. Such samples are exceedingly difficult to machine, nearly as much so as hardened carbon-steel; yet the latter with the same load would show no appreciable change. Mild steel would shorten about 50 per cent.; hard unquenched carbon-steel, about 25 per cent. of its length.

It is therefore difficult to describe the exact degree of hardness possessed by manganese-steel, and it is not always possible to predict

TO MANGANESE STEEL.

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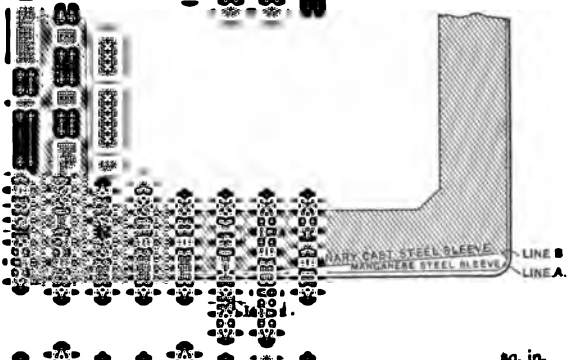

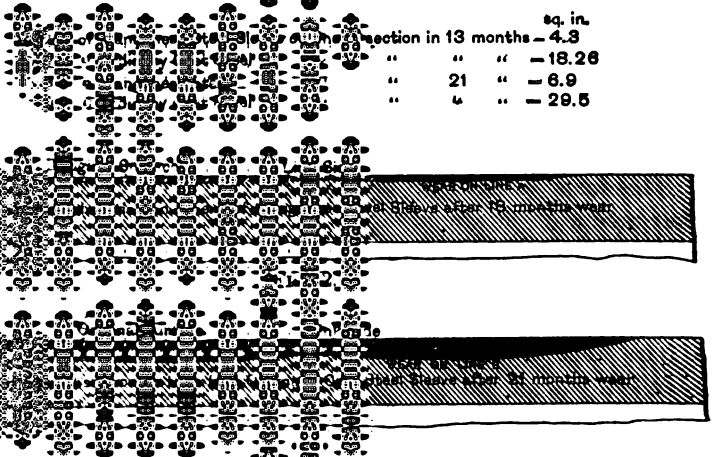

Manganese-Steel Sleeves.

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ven excellent service in the

majority of cases where it has been used for parts of crushing and grinding machinery.

Messrs. John Mowlem & Co., of Guernsey, have used manganese-steel for the cheeks of Blake crushers, and report that after crushing 3000 tons of a very hard class of stone "their present condition is very little different from what they were when first put in, whereas cast-iron cheeks will only crush 300 tons before being worn out."

Messrs. Darbishires, of the North Wales Granite quarries, at Penmaenmawr, say that the manganese-steel plates of their Blake crushers after outlasting three pairs of cast-iron ones, were still not worn out.

At the Hecla works of the writer's firm, a pair of manganese-steel edge-runner rings 5 feet 2¼ inches diameter, 15¾ inches face, have been tested in a mill used for grinding up hard silica bricks, quartz, and other material of similar nature. It is too soon to say what will be their life; but after running for seven months and crushing 409 tons of the material named above, they have only worn down ⅝ inch in diameter, that is, $\frac{5}{16}$ inch of the thickness of each side; while a pair of cast-iron rings 5 feet 3⅝ inches diameter, used on similar work, after crushing 109 tons only had worn down ¾ inch in diameter. These are shown in Table III. A.

TABLE III., A.

Material.	Original dimensions. Ft.	In	Present dimensions. Ft.	In.	Quantity ground. Tons.	Reduction in diameter. In.
Manganese-steel rings, .	5	2¼	5	1⅛	409	⅝
Best cast-iron rings, .	5	3⅝	5	2⅝	109	¾

A large roller-path of manganese-steel, for a cement-mill, is reported by the users, the Arlesey Cement Company, near London, to show no signs whatever of wear, after five months' continuous work.

For this class of work, such as edge runner rings and bottom-plates, jaws, faces, toggle-plates and cheeks of stone-breakers, parts of disintegrators, balls, toothed-gearing for breaking up anthracite coal, rolls and similar articles, the use of this new steel will be found to give greater economy by reducing renewals, permitting higher speeds and more work to be got out of the same machine, as well as preventing breakages.

There has been already a considerable application of manganese-steel balls for crushing machinery. By a new method of manufacture it is now possible to produce these articles at a cheap rate and yet obtain a sound homogeneous ball of any required diameter.

Elevator-Links.—An important use in America, where so much

elevator-work of all classes is done, should be the employment of manganese-steel for elevator-links. In England they have been adopted by several firms for coal-elevators, where the wear and tear is especially heavy. The Manvers Main Colliery Company, in the South Yorkshire coal-field, reports that after four years the manganese-steel links had been found far superior to ordinary steel links and would last three times as long as the latter. The durability, being so great as compared with ordinary steel, should be still greater as compared with malleable iron.

Owing to the non-magnetic qualities of the manganese-steel it has been found very useful for freeing electrical driving-chains.

Agricultural Work.—There are no uses where durability and strength are more requisite than in parts of agricultural implements. In remote parts of a country, especially where skilled labor is not easily available, it is of the utmost importance that the tools employed should possess the greatest possible durability. Here, again, therefore, manganese-steel offers a wide field for employment, its hardness, though not equalling that of the chilled iron, rendering it as serviceable as very hard cast-iron, without the liability of the latter to sudden fracture.

Shares, fingers, plow-points, and other articles made of manganese-steel have given good results, and quite recently spades, shovels, rakes, hoes, and forks have been introduced. A Sheffield maker of such articles reports the opinion, from the tests he has already made with ordinary steel, that these implements, if made of manganese-steel, would outlast from four to six of ordinary steel.*

A manganese-steel entrenchment-shovel, only 0.1 inch thick, was recently tested by firing at it nickel projectiles from the new English magazine rifle, which has a specially high velocity. At the short range of 100 yards the projectiles were unable to penetrate, and even when propelled by the cordite powder the penetration was incomplete at 200 yards. A shovel made of ordinary steel would have been easily pierced at five times, or if cordite explosive were used at nine or ten times this distance. The manganese-steel carried off the honors by being not only more durable as regards its use for entrenching purposes, but also acting as an excellent shield-plate.

Wheels.—Whatever may be the objections to forged manganese-

* Messrs. John Bedford & Sons, Sheffield, who make large numbers of spades, shovels, and forks, report that so far as they have tested samples of manganese steel they believe they will outlast three or four made of ordinary steel.

steel for tires and axles, on account of the difficulty in machining it, this does not apply to cast manganese-steel, whether in wheels for railroads (engine, freight, and passenger), horse-cars, mining-wagons, or other classes of rolling stock. In car-wheels it has already given excellent mileage-returns. The difficulty of obtaining in the hard manganese-steel a satisfactory and smooth hole for the axle-fit was overcome by casting in the hubs a bush of soft material, or forcing in liners by hydraulic pressure.

English locomotive practice still adheres persistently to an expensive built-up wheel (though now wisely adopting cast-steel as a material for the centers of locomotive and other railroad wheels). It is therefore not possible at present to bring forward any definite English evidence as regards railroad practice with manganese-steel wheels. But the writer's firm has had in use on English railroads ordinary cast-steel wheels of solid construction, that is, cast complete in one piece, which have given no less than 120,000 miles service and are still good for much longer life. With the hardness of manganese-steel it is more than probable that 300,000 to 400,000 miles could readily and with perfect safety be attained.

A considerable number of horse-car wheels have been in use with satisfactory results, but here, owing to the cheapness of cast-iron wheels (not nearly so economical as many suppose, owing to the many breakages which pull down the average), headway is only just beginning to be made. As regards mileage, the manager of the Chester Tramways reported that 65,000 miles had been obtained with manganese-steel wheels. This is a high result for street-car service, but there is no reason, in view of the hardness of the steel, why it should not be obtained regularly.

It need hardly be said that a well-designed wheel of manganese-steel should be an excellent one for regular railroad service, and the American licensee of this steel, the Taylor Iron and Steel Company, High Bridge, N. J., has obtained some remarkable results under the drop and other tests.

Tests of Manganese-Steel Car-Wheels.—A 33-inch manganese-steel disc-wheel, made by them under the Hadfield system, was placed horizontally upon supports, and a tup weighing 1120 pounds was allowed to fall fifty-four times upon the hub, when the latter was knocked loose on one side, but the wheel was still in one piece.

Another 33-inch manganese-steel wheel of armed design was dropped as follows upon a hard cast-iron foundation embedded in the ground.

TABLE IV.

2 drops, 5 feet each, ...	Sum of the drops, 754 feet.
2 drops, 10 feet each, ...	
2 drops, 15 feet each, ...	
2 drops, 20 feet each, ...	
2 drops, 25 feet each, ...	
18 drops, 30 feet each, ...	
2 drops, 32 feet each, ...	

Notwithstanding this severe test, the wheel was only slightly cracked in two spokes and on the edge of the tire, and remained unbroken.

A 20-pound sledge-hammer test was made on an armed wheel at High Bridge, N. J., last January, when the thermometer was considerably below zero, the wheel having been left out all night in the open air, and 150 blows were given without any effect except to slightly bend down the flange. The same wheel was, at the same time, further tested, sustaining 34 blows of a tup weighing 1120 pounds, dropping from a height of 12 feet before cracking. These, with previous severe tests of similar nature on manganese-steel castings, made by the mechanical engineer of the Pittsburgh, Cincinnati and St. Louis Railroad, conclusively prove that manganese-steel is not brittle even at extremely low temperatures.

When it is considered that the best qualities of cast-iron car-wheels of similar design will not stand dropping more than about eight times from a height of 15 feet without breaking (in many cases not four times), it will be seen that the extraordinary combination of hardness and toughness of manganese-steel must, before long, make it specially valuable for this class of work.

Similar results have also been obtained at the Hecla Works with some light manganese-steel disc-wheels, 2 feet in diameter. The results with two wheels which were tested by being dropped at varying heights upon a large steel ingot are shown in Table V.

TABLE V.

No. 1505 No. 2.	3 blows. 2 " 2 " 2 " 6 " 24 "	3 ft. each. 5 " 7 " 10 " 25 " 30 "	Sum of the drops, 923 ft.	This wheel is still unbroken, being only slightly bulged on disc.
No. 1505 No. 1.	3 blows. 2 " 2 " 2 " 2 " 2 " 2 " 20 "	3 ft. each. 5 " 7 " 10 " 15 " 20 " 25 " 30 "	Sum of the drops, 773 ft.	Small crack in one of the disc-plate holes. This wheel was then laid flat, and a tup weighing 2850 pounds dropped from 5 and 10 ft. respectively, the disc and rim cracking.

The rim of wheel No. 1505, No. 2, was then drilled in comparison with several other carbon-steel wheels of varying hardness. The results are shown in Table VI. Diameter of hole in each case, $\frac{1}{4}$ inch. Drill, special high-class tool-steel.

TABLE VI.

Material drilled.	Mark.	Time occupied in minutes.	Weight of drillings, in grammes.	Grammes per hour.
Rim of manganese steel disc wheel...	1505 No. 2	15	10.52	42
Hard turning tool-steel.....	412	5	60.26	723
Rim of hard carbon (.80 pr. ct.) steel disc wheel.....	1084	5	85.44	1025
Medium cast-steel (.45 per ct. C).....	8	5	94.84	1138
Mild forged-steel (.25 pr. ct. C).....	104	5	109.30	1211

There is thus obtained a manganese-steel wheel, neither forged nor rolled, which notwithstanding 923 feet, sum of drops, is still unbroken, yet under the drilling test only loses 42 grammes per hour against 1138 grammes of ordinary cast-steel, or 1025 grammes of hard carbon steel, containing 0.80 per cent. carbon.

The hardness of manganese-steel thus proved has been utilized for rivets by safe manufacturers in England. One of the leading firms there reports: "Our chisels won't touch it. We know this to our cost, as in a safe we made 18 months since, wholly riveted up by manganese-steel rivets, one was not properly closed, and in an endeavor to cut off the part projecting we destroyed two dozen chisels, and had to leave the projection on after all."

For mining-wagons, very successful results have already been obtained in America and England. The Lehigh & Wilkesbarre Coal Company reports that the manganese-steel wagon-wheels, after a year of the hardest service, having been in use where they were constantly being spragged and slid down long slopes of steep incline, have so far shown no perceptible signs of either flattening or wearing. This company has also found these wheels 33 per cent. lighter than those of cast-iron, besides being free from breakages. Even at the higher first cost, manganese-steel has proved more economical than the best chilled iron wheels, which rapidly wear out or break in collisions, runaways, or other troubles of the kind constantly experienced in mining.

Similar results have been obtained by many other users. In Great Britain it would not be possible in the underground workings, often very long, and usually at great depths from the surface, to obtain the necessary output with tubs or wagons having cast-iron wheels, which are not only heavy and cumbersome, but are constantly breaking. The large outputs of modern collieries, especially those worked, as the majority are in England, by deep shafts, are dependent upon a continuous and uninterrupted output of coal from the different parts of the workings, some of them several miles from the pit-shaft. In the days of cast-iron wheels, breakages were constantly occurring, and large outputs could not be obtained with regularity. A single wheel breaking may lead to endless confusion in that particular working by causing 20 or 30 corves or wagons to get off the line, and blocking communication for many hours.

The writer's firm in Sheffield has supplied 20,000 cast-steel wheels to one firm of colliery proprietors, Messrs. Newton, Chambers & Company, of the Thorncliffe Collieries, South Yorkshire. Mr. A. M. Chambers, managing director of these collieries, and one of the leading mining engineers in the South Yorkshire district, says in a recent letter that during the last seven or eight years he does not recollect having one of the above wheels break in service, and he has no hesitation in saying that if his firm had to go back to the use of cast-iron wheels instead of steel, it would very materially reduce the large output of coal. He estimates the reduction in output to be at least 10 per cent. when breakages with cast-iron wheels are of daily occurrence. In fact, with the latter class of material it was not safe to have the "pits" worked by fast haulage, the breakages being so serious.

The writer's firm has turned out at least 2,000,000 of the Hadfield cast-steel wheels (carbon steel) for colliery and similar purposes; but it is now believed that, as the carbon-steel was found immeasurably superior to cast-iron, so manganese-steel will prove still better. In manganese-steel wheels the same advantage of lightness is obtained as with those of ordinary cast-steel, but the former is stronger and its durability is probably at least three to five times greater.

Results of Tensile, Drop, and Other Tests of Forged Manganese-Steel.

This material has been subjected to tests by independent authorities, including such names as Mr. David Kirkaldy, the father of scientific methods of testing; Professor Kennedy, the well-known London

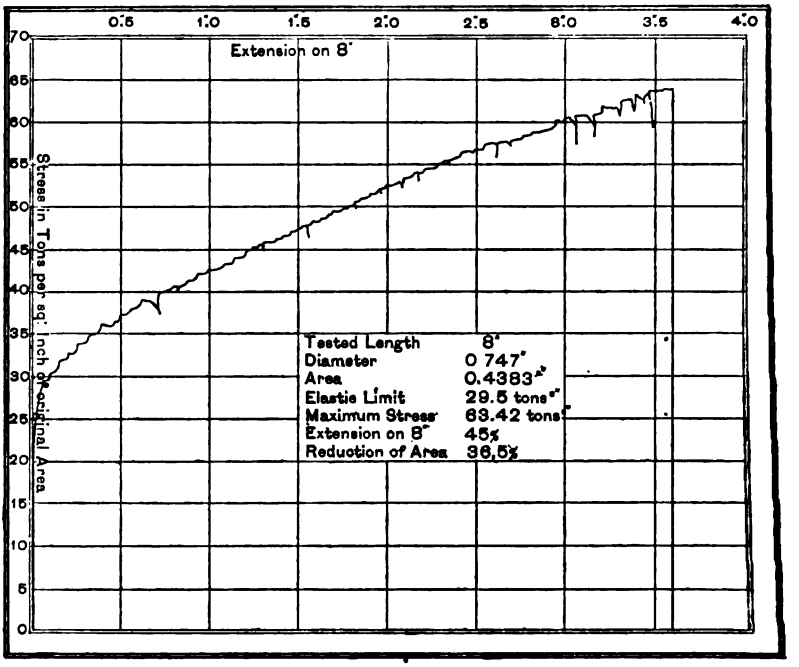
		1290 F	Tested as forged.			.780	.477			41.84	3.30		Grand. sr.		
Brown, Bayley's Steel Works, Ltd., Sheffield.	Oct., '92	1291 F	Air-toughened.	1.08	13.35	.780	.477	10″	.....	45.60	13.90	14.80	Fine grain.	Air-toughened.	
		1292 F				.780	.477			46.50	16.70	17.10			
		1293 F	Water-toughened.			.780	.477			63.83	43.00	40.80	Silky.	Water-toughened.	
		1294 F				.780	.477			69.48	49.20	38.80			
		1295 F													
Jno. Brown & Co., Ltd., Sheffield, for Capt Tresidder.	May, '92	959 F	Water-toughened.	1.10	13.33	.....	.....	8″	.....	73.80	24.00	32.00		Badly piped down center. Pipe down one side.	Special attention is drawn to the high tensile strength. The elongation, probably owing to insufficient toughening, was lower than usual.
		960 F								70.20	20.00	42.00			
		961 F								68.60	23.00	45.00			
W. H. Stanger, M. I. C. E., Westminster Test'g Works, London.	June '92	1424 F	Water-toughened.	1.15	12.61	.747	.438	8″	29.5	63.42	45.00	36.50		An autographic strain-stress diagram has been taken of this specimen. (See Plate V.)	
		1431 F		1.43	12.52	.741	.431		29.9	62.84	38.30	30.00 Ap.			

The above independent tests by steel manufacturers, locomotive engineers, experts in testing, and others, give full proof of the remarkable uniformity of this material, with regard to both ductility and tenacity.

engineer; the late Mr. J. F. Barnaby; Mr. Stanger, of the Westminster Testing Works, London, and others. Table VII. gives a condensed summary of tests. The full and detailed tables of Kirkaldy are referred to later.

Professor Kennedy obtained a tenacity of 63 tons per square inch with 42 per cent. elongation on 8 inches. His result indicates a peculiar strained condition of the forged and water-quenched manganese-steel. This has nothing to do with the real permanent set or yielding-point, as Professor Kennedy found it was entirely removed

PLATE V.



Automatic Strain-Stress Diagram of Forged and Toughened Manganese-Steel.

when a second time tested with the high load of 60,000 pounds per square inch. He says: "The whole extensions were then wholly elastic, the peculiar permanent set first noticed disappearing."

In June last, Mr. Stanger, M.I.C.E., of the Westminster Testing Works, London, took for the writer an autographic strain-stress diagram on a 50-ton Wicksteed-Buckton testing-machine. There has been perhaps, in the history of steel no more interesting autographic record than that shown by Plate V., giving the results of the above test. The breaking-strength was 63.42 tons (142,000 pounds) per

square inch, elongation 45 per cent., and reduction of area 36 per cent. It is specially interesting to trace, as is only possible in an autographic record, the behavior of this peculiar material under such a high stress as is ordinarily obtained only with hardened and tempered steel, yet at the same time showing extraordinary ductility—more than mild steel—increasing its length nearly 50 per cent. cold. The peculiar strained condition of the water-quenched material is shown by the wavering line on the diagram. It will be noticed that there is a slight deviation or permanent set at about 20 tons, but it is not until 25 tons is reached that there is any marked yield-point, in fact, this appears to be nearer 30 tons. This is the stress returned in the report by Mr. Stanger, viz., 29.50 tons (66,080 pounds) per square inch as the elastic limit.

Another sample pulled in two at the same testing-laboratory showed a breaking-strength of 62.84 tons (140,760 pounds) per square inch, with elastic limit of 29.90 tons (66,980 pounds), and elongation of 38.30 per cent. One-half of this tested bar was reheated and quenched. It then bent double cold, showing that the material after water-quenching was in no way injured by the previous severe stress (140,760 pounds). Whatever may be the nature of the action upon such a material by the high stress to which it has been submitted, the internal structure and crystallization do not seem to be in any way injuriously affected.

A very complete set of tests of manganese-steel was also made for the writer's firm about eighteen months ago by Messrs. D. Kirkaldy & Sons, of the Testing and Experimental Works, London. Mr. David Kirkaldy's reputation in this class of work makes these tests of more than usual value.

They comprise the following:

Table VIII. shows the results obtained from four specimens of water-toughened manganese-steel. It gives the elastic and ultimate tensile strength, ratio of elastic to ultimate contraction of area, total elongation, as well as extensions and sets with stresses of 60,000, 80,000 and 100,000 pounds per square inch respectively.

Table IX. gives the resistance to bending stress of forged, air-toughened and water-toughened manganese-steel, including elastic and ultimate strengths.

Table X. gives the resistance to thrusting stress.

Table XI. gives the resistance to deflection and the set produced under a gradually increasing bending stress on a manganese-steel bar (water-toughened) 5¼ inches in diameter. Owing to the high stress

TABLE VIII.—*Manganese-Steel (Analysis: C 1.00 pr. ct., Mn 12.20 pr. ct.). Results of Experiments to Ascertain the Elastic and Ultimate Tensile Strength, etc., of 4 Forged-Steel Bars Received from Messrs. Hadfield's Steel Foundry Company.*

Test No.	Description.	Original. Diam.	Original. Area.	Stress. Elastic. per sq. inch.	Stress. Ultimate per sq. inch.	Ratio of Elastic to Ultimate.	Contract'n of area at Fracture.	Extension, sets at—length, 10 inches. 60,000 lbs. per sq. in.	80,000 lbs. per sq. in.	100,000 lbs. per sq. in.	Ultimate.	Appearance of Fracture.
Z.	1⅝ dia., heads 2″ sq.	Inches. Forged	Sq. in.	Lbs. Tons.	Lbs. Tons.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
3028	Water-toughened. F. W. 2458	1.35	1.431	45,500	137,7..0	33.0	36.0	0.46	6.04	17.7	41.3	75 p. c. silky. 25 p. c. gran'r.
3029	Water-toughened. F. W. 2459	1.37	1.474	43,800	132,463	33.1	33.2	0.61	7.42	19.9	40.0	70 " " 30 " "
3030	Water-toughened. F. W. 2460	1.35	1.431	44,600	132,621	33.6	33.6	0.62	6.58	18.2	38.3	60 " " 40 " "
3031	Water-toughened. F. W. 2461	1.37	1.474	43,500	124,383	35.0	34.3	0.63	8.39	20.4	37.1	60 " " 40 " "
	Mean			44,350—19.8	131,804—58.8	33.7	34.3	0.58	7.11	19.0	39.2	66 " " 34 " "

Tested with forged surfaces—collars being the only part machined.

TABLE IX.—*Manganese-Steel (Analysis: C 1.00 pr. ct., Mn 12.20 pr. ct.). Results of Experiments to Ascertain the Resistance to Bending Stress of 6 Forged-Steel Bars Received from Messrs. Hadfield's Steel Foundry Company.*

Distance between supports, 20 inches.

Test No.	Description.	Size.	Stress. Elastic total.	Stress. Ultimate total.	Ratio of Elastic to Ultimate.	Deflection at— 20,000 Lbs.	25,000 Lbs.	30,000 Lbs.	35,000 Lbs.	40,000 Lbs.	Ultimate.	Angle.	Effects.
Z.	2″ square 25″ long	In. B. D.	Lbs.	Lbs.	Per cent.	In.	In.	In.	In.	In.	In.	Degrees.	
3047	F. 2418	1.95 × 1.99	17,600	44,145	39.9	.130	.232	.516	1.17	2.30	5.10	60	Broken granular, fine.
	"Just as forged"	B D² = 7.72	[18,238]	[45,746]									
	"Air-toughened"												
3048	F. A. 2449	1.97 × 1.98	17,600	41,460	42.5	.132	.243	.542	1.12	2.11	2.80	30	Broken granular, fine.
		B D² = 7.72	[18,238]	[42,964]									
3049	F. A. 2450	1.97 × 1.97	17,000	41,470	41.0	.131	.265	.587	1.22	2.43	2.90	31	Broken granular, fine.
		B D² = 7.64	[17,801]	[43,424]									
	Mean.		17,300	41,465	41.7	.131	.254	.564	1.17	2.27	2.85	30	
			[18,019]	[43,194]									
	"Water-toughened"												
3050	F. W. 2451	1.97 × 1.99	9,500	39,700	23.9	.189	.323	.708	1.80	.....	.....	160	Cracked.
		B D² = 7.80	[9,714]	[40,718]									
3051	F. W. 2452	1.98 × 1.98	9,500	39,670	23.9	.197	.334	.798	1.81	.....	.....	154	"
		B D² = 7.76	[9,791]	[40,897]									
3052	F. W. 2453	1.96 × 1.96	8,900	38,875	22.9	.199	.340	.787	2.15	.....	.....	150	"
		B D² = 7.53	[9,196]	[41,206]									
					23.6	.195	.332	.764	1.92	.....	.....	155	
	Mean.		9,300	39,385									
				[40,940]									

...calculated upon standard size of 2.00 × 2.00 in., or B D² = 8.00.

... bars received from Messrs. Hadfield's Steel Foundry Company.

Thrusting Stress.

Test No	Description.	Dimensions.			Stress, elastic per sq. in.	Depression at—			Effects.	Specific Gravity.			
		Length.	Diam.	Area.		50,000 lbs. per sq. in.	100,000 lbs. pr. sq. inch.	150,000 lbs. pr. sq. inch.		Weight— In Air.	In Water.	Difference.	Specific gravity.
Z.	1⅜ in. diam., 2 in. long.	Inches.	Inches.	Sq. in.	Lbs.	Per cent.	Per cent.	Per cent.		Grammes.	Grammes.	Grammes.	
3041	F. 3222 Just as forged	1.869	1.34	1.410	58,100	0.37	6.63	13.54	Slightly barreled	338.804	295.739	43.065	7.8673
3042	F. 3223 Just as forged	1.982	1.34	1.410	58,000	0.35	6.00	12.76	"	362.872	316.749	46.123	7.8675
				Mean	58,050	0.36	6.31	13.15				Mean	7.8674
3043	F. A. 3224 Air-toughened	1.940	1.34	1.410	54,000	0.46	7.58	14.28	"	352.679	307.841	44.838	7.8656
3044	F. A. 3225 Air-toughened	1.914	1.33	1.389	54,100	0.42	7.47	14.11	"	345.276	301.350	43.926	7.8604
				Mean	54,050	0.44	7.52	14.19				Mean	7.8630
3045	F. W. 3226 Water-toughened	1.887	1.34	1.410	59,000	0.37	7.00	13.78	"	339.832	296.607	43.225	7.8619
3046	F. W. 3227 Water-toughened	1.920	1.33	1.389	59,000	0.42	6.67	13.54	"	346.546	302.463	44.083	7.8612
				Mean	59,000	0.39	6.83	13.66				Mean	7.8615

THRUSTING STRESS.

Test No	Description.	Dimensions.			Stress.		Ratio of Elastic to Ultimate.	Depression at—			Effects.
		Length.	Diam.	Area.	Elastic per sq. inch.	Ultimate per sq. inch.		50,000 lbs. per sq. inch.	60,000 lbs. per sq. inch.	70,000 lbs. per sq. inch.	
Z.	1⅜ in. diam., 10 in. long.	Inches.	Inch.	Sq. in.	Pounds.	Pounds.	Per cent.	Per cent.	Per cent.	Per cent.	
3035	F. 3075 Just as forged	10.00	1.34	1.410	56,000	71,787	78.0	0.16	0.39	1.90	Buckled.
3036	F. 3076 Just as forged	9.97	1.34	1.410	60,200	77,667	77.5	0.13	0.23	0.88	"
				Mean	58,100	74,727	77.7	0.14	0.31	1.39	
3037	F. A. 3077 Air-toughened	9.88	1.34	1.410	53,300	67,847	78.6	0.18	0.81	.....	"
3038	F. A. 3078 Air-toughened	10.01	1.34	1.410	53,000	67,060	79.0	0.20	0.82	.....	"
				Mean	53,150	67,453	78.8	0.19	0.81	.....	
3039	F. W. 3079 Water-toughened	9.82	1.34	1.410	52,600	67,347	78.1	0.24	0.51	.....	"
3040	F. W. 3080 Water toughened	9.79	1.34	1.410	52,100	64,560	80.7	0.31	0.77	.....	"
				Mean	52,350	65,953	79.4	0.27	0.64	.....	

Tested with forged surfaces—the ends only being machined.

required, Mr. Kirkaldy thought it unwise for the safety of his testing apparatus to deflect the bar more than 15 inches. It was then removed unbroken. The results of the deflection up to this point may be of interest.

TABLE XI.—*Result of Experiment to Ascertain the Resistance to Deflection and the Set, under a Gradually Increased Bending Stress, of a Forged Bar of Water-Toughened Manganese-Steel from Messrs. Hadfield's Steel Foundry Company, Limited.*

Length of bar, 7 ft. 11¼ in.; diameter, 5.2 in.; weight, 569 lbs.; mark, F.W. 2446 composition, C 1.00 per cent.. Mn 12.20 per cent.; span, 6 ft. 6 in.; load applied at center; test number, Z. 3053.

Stress in thousands of pounds	22	24	26	28	30	32	34	36
Stress in tons (2240 lbs)	9.82				13.39			
Deflection in inches	0.23	0.26	0.29	0.33	0.36	0.40	0.43	0.47
Set in inches								
Stress in thousands of pounds	38	40	42	44	46	48	50	52
Stress in tons (2240 lbs.)		17.85					22.31	
Deflection in inches	0.51	0.56	0.59	0.64	0.69	0.73	0.80	0.83
Set in inches		0.25					0.38	
Stress in thousands of pounds	54	56	58	60	62	64	66	68
Stress in tons (2240 lbs.)				26.78				
Deflection in inches	0.88	0.94	1.00	1.06	1.13	1.20	1.27	1.35
Set in inches				0.57				
Stress in thousands of pounds	70	72	74	76	78	80	82	84
Stress in tons (2240 lbs.)	31.25					35.71		
Deflection in inches	1.47	1.53	1.62	1.77	1.90	2.15	2.34	2.64
Set in inches	0.86					1.44		
Stress in thousands of pounds	86	88	90	92	94	96	98	100
Stress in tons (2240 lbs.)			40.17					44.64
Deflection in inches	2.94	3.42	4.01	4.54	5.34	6.35	7.30	8.15
Set in inches			3.19					
Stress in thousands of pounds	102	104	106	107.08				
Stress in tons (2240 lbs.)			47.32	47.80				
Deflection in inches	8.77	9.90	10.97	15.00				
Set in inches								
Elastic limit in tons	12.5							
Maximum stress applied in tons	47.80							
Ratio of elastic limit to ultimate stress	26.1							
[Bar removed unbroken.]								

After these results in the testing machine it is not surprising to

find that some very remarkable tests have also been obtained with forged and toughened manganese-steel in axles and tires.

As regards the shaping and finishing of the journals in axle-forgings, these can be swaged very near to finished dimensions. By means of special tools, with suitable grinding attachment, there need be no real difficulty in meeting this point. In tires for built-up wheels the objection is more serious, the amount of machining being greater and also very difficult, at any rate, so long as built-up tired wheels are constructed as at present. Moreover, the extraordinary toughness of the cheaper cast manganese-steel wheels, described previously, makes them advantageous as compared with the expensive built-up wheel.

The following details of experiments are given, therefore, not for the purpose of proving that the material can be used with advantage at present, or at any rate for tires, but to illustrate its remarkable combination of stiffness, great toughness, and hardness.

Axles.—A manganese-steel axle $5\frac{1}{8}$ by $4\frac{1}{8}$ inches in diameter in center and 6 feet $11\frac{3}{4}$ inches in length, was forged to ordinary railway freight-car pattern. No difficulty of any kind was experienced in this operation. It was very malleable, though specially tough and dense, offering more resistance to blows of the hammer than is usual with this steel. It was an excellent forging, free from imperfections, and of specially smooth appearance. The journals could have been brought to the finished dimensions with very little grinding or other fitting. The supports were 3 feet 6 inches apart and the weight of drop used was 1640 pounds.

After water-quenching, it was sent to High Bridge, N. J., and there tested by the Taylor Iron and Steel Company.

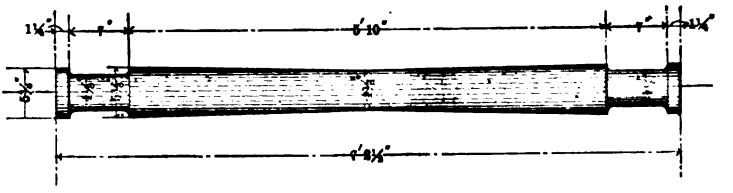
TABLE XII.

No. of blow.	Height in feet.	
1	25	Deflection $7\frac{1}{2}$ inches.
4	25	Deflection $1\frac{1}{4}$ inches.
9	25	Deflection 6 inches.
12	25	Deflection $1\frac{1}{2}$ inches.
20	25	Deflection not noted after twelfth blow.
21	30	
22	30	Cracked.
33	30	Broke.

That is 20 blows from 25 feet.
and 13 blows from 30 feet.
—
33 in all.

Weight of tup 1640 pounds.
Axle reversed after each blow.

The Brown-Bayley's Steel Works Company, of Sheffield, tested for the writer a manganese-steel axle of the dimensions shown in the following sketch:

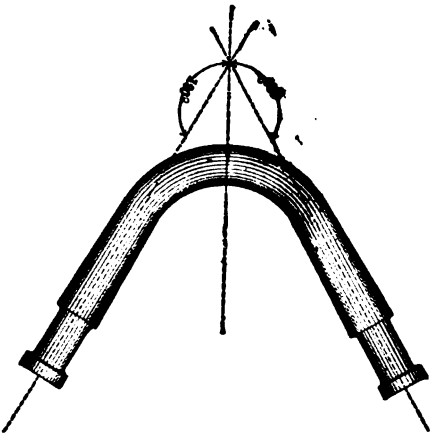


This axle was tested with a 2000-pound tup, supports 3 feet 6 inches apart, and reversed after each blow.

TABLE XIII.

No. of blows.	Height of drop. Feet.	Average deflection. Inches.
6	20	$3\frac{1}{8}$
4	25	$3\frac{1}{4}$
6	30	$3\frac{3}{4}$
10	32	4
26		

After the 21st blow, the blows were delivered on one side, the axle not being reversed. The axle was thus deflected $9\frac{3}{4}$ inches at the 26th.



After the above test the axle was bent in a hydraulic press to 120 degrees, when a crack was discovered.

In view of the weight of the tup and the comparatively small de-

flections produced, the above is an exceedingly severe test. One of the strictest tests on ordinary carbon-steel axles of best quality is that made for the New South Wales Government under Sir John Fowler's inspecting engineer's instructions, viz.: four 20-feet, four 25-feet, and four 30-feet blows of a 2000-pound tup, which the axle must stand without showing signs of fracture. The manganese-steel axle stood more than twice this, and then bent at 120 degrees before showing slight cracks.

Tires.—Brown-Bayley's Steel Works Company tested also two manganese-steel tires, the material for which was made at the Hecla Works. Considerable difficulty was experienced in producing the tire to shape, that is, during the forging and rolling processes, owing to the toughness of the material when hot. The tires were first water-toughened and a 2240-pound tup dropped on one of them as shown in Table XIV. This tire is shown in Fig. 2, Plate I. (page 164) and sketch in Table XIV.

TABLE XIV.

Size of tire: 2 feet 8 inches internal diameter by 5½ inches wide by 2½ inches thick. Weight of tup, 2240 pounds.

Height of fall in feet.	Deflection in inches.	
10	$1\frac{5}{16}$	The tire was afterwards placed
12	$2\frac{7}{16}$	under the hydraulic press and
14	$3\frac{1}{8}$	bent as per sketch.
16	$5\frac{1}{16}$	
18	$6\frac{1}{8}$	
20	$7\frac{1}{4}$	
22	$10\frac{1}{4}$	
24	$12\frac{1}{2}$	
26	$14\frac{1}{2}$	See also Fig. 2, Plate I.
28	16	
30	18	
32	$20\frac{1}{2}$	
32	$22\frac{3}{4}$ unbroken.	

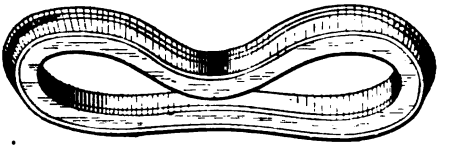


Table XV. gives tests of a manganese-steel tire for which the **steel was** produced at the Hecla Works, Sheffield, and rolled by the **Superintendent** of Locomotive Power, L. & Y. Railway, Harwich.

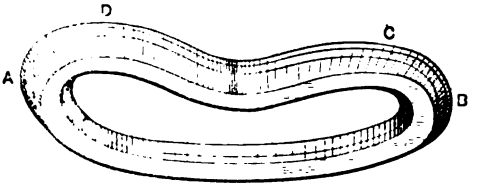
TABLE XV.

No. of blow.	Height. Feet.	Deflection. Inches.	
1	5	⅜	After ninth blow tire turned
3	15	¾	over and received blows
6	30	1⅜	from opposite side.
9	30	1⅜	
12	30	1⅜	
15	30	1⅜	

Sum of drops, 375 feet.
Total deflection, 20¾ inches.
Tire not broken.

It was then nicked at A and B with difficulty, received three blows from 30 feet at C, cracking at B 1½ inches into the tire, and after five more blows at D, the tire was completely broken at A and B.

Mr. P. H. Dudley, of New York, has said of this material: "A tire made of manganese-steel so hard that it can hardly be machined, to stand such severe drop-tests as named without failing, and only breaking after being nicked, does much to correct our erroneous impressions that a hard metal must of necessity be brittle. That a metal may be hard and tough is one of the most important facts for consumers of steel to learn to-day. If there can be produced a tire of largely increased strength over the ordinary tire, safe beyond



question, having three or four times the present wearing-capacity there would be a great need in railroad service for such tires, irrespective of any increased first cost per pound of metal."

Mr. Dudley's wide experience entitles his remarks to special consideration, and the facts above mentioned necessarily apply just as much to a cast as a forged manganese-steel.

ELECTRICAL CHARACTERISTICS.

Non-Magnetic Character and Its Bearing Upon the Beta-Iron Theory.—A peculiar fact noticed in this material is that when exceeding about 12 per cent. manganese, it is practically non-magnetic, even when submitted to the strongest magnetizing forces. This was

tested by the writer some time ago when going through the Edison laboratories. A large magnet capable of lifting nearly a ton weight would not even attract a piece of manganese-steel weighing but a few grammes. Even the 9 per cent. material is non-magnetic, taken in bulk, though its drillings are influenced considerably, thus indicating that to detach the material or break it up into smaller masses enables the magnetic force to exert its influence. This, however, does not apply or only very slightly to 13 per cent. drillings.

No satisfactory explanation of the non-magnetic qualities of this steel has yet been brought forward, though the material has been examined by most of the leading scientists of the day. It is certainly remarkable that iron which, in the form of carbon-steel, makes the best permanent magnets becomes, when existing as an alloy or combination of manganese, practically non-magnetic.

Some years ago the writer noticed that some manganese-steel carwheels which had been running for a considerable period were, after their return, more susceptible to magnetic influence. Unfortunately a record had not been kept of the exact percentage in these particular wheels. Probably it was not more than about 11 per cent., this amount having been employed in some of the earlier experiments connected with manganese-steel castings. It would seem that the constant vibration experienced by such articles had to some extent influenced the particular property under consideration. This fact is not conclusive, for the writer has seen other wheels apparently as non-magnetic after several years of use as when first put to work.

Manganese-Steel Magnetic Under Certain Circumstances.—Quite recently, however, the writer has discovered some further peculiar properties of this material. It would appear that under certain circumstances it can become susceptible to magnetic forces.

A bar, 1¼ inches square by 12 inches long, and of the usual non-magnetizable quality, was heated for twenty-one days by Messrs. T. Sorby & Sons in a Sheffield cementation-furnace of ordinary construction, being packed in charcoal along with bars of Swedish iron. Table XVI. shows the composition.

TABLE XVI.

	C.	Mn.	
Before treatment, . .	1.08	13.08	Non-magnetic: not attracted by magnet; and a very sensitive ship's compass was not affected in the slightest degree.
After treatment, . .	1.29	.....	Compass strongly deflected; and though not strongly affected by the magnet there was a distinct effect.

Although the analysis indicates that the carbon was but little increased, a remarkable change occurred, the sample having by cementation become susceptible to magnetic influence. The needle of a compass not previously affected in the slightest degree was now strongly deflected, nearly as much so as by samples of ordinary unmagnetized iron and steel. This was an interesting result; but the next portion of the experiment was still more so. The same bar, 1¼ inches square, was heated at one end, forged down into a thinner section, ½ by ⅛ inch, raised to a yellow temperature (about 1000° C.) water-quenched and bent double cold as is usual with the manganese-steel under this treatment. This portion had again become non-magnetic. Thus in the same bar there resulted one portion unaffected by strong magnetic influence, while the other portion was susceptible to a considerable degree. So far as at present ascertained, the other physical properties of the material before and after treatment appeared to differ but little. Its hardness was the same, its fracture was but little changed. The cementation had but slightly increased the carbon, from 1.08 to 1.29 per cent., which is not sufficient to cause an expectation of any marked difference. The writer's firm has produced indiscriminately, with 1 or 1¼ per cent. carbon in the 13 per cent. manganese steel, a material possessing physical properties which differ but slightly.

The sample as received from the cementation-furnace appears similar to ordinary forged manganese-steel. Previous to water-quenching it is somewhat brittle, but the latter treatment at once restores the toughness, at the same time destroying the magnetic qualities acquired by the long heating, at a comparatively low temperature (about 800° C.) of cementation. The duration of the heating is evidently the chief factor, the acquired magnetic qualities of a previously non-magnetic steel being at once permanently lost by reheating and quenching. The same fact was noticed (see Table XVII.) after heating a sample of manganese-steel which had been annealed in a malleable cast-iron annealing-furnace.

TABLE XVII.

Sample before annealing,	.69 C, 13.93 Mn.
Sample after annealing,	.03 C, ... Mn.
Original sample,	Non-magnetic.
After annealing,	Strongly magnetic.
After annealing, re-heating, water-quenching and re-heating,	Strongly magnetic.

This sample being not more than ⅛ inch thick was considerably

oxidized. The scale was carefully removed before testing the sample for magnetic qualities. Thicker samples are now under examination by the same tests. This sample did not become again magnetic by water-quenching, but further experiments are in hand on this point.

As it would take up too much time and space to discuss this interesting question here fully, the writer merely states the results.

Bearing of Foregoing on Beta-Iron Theory.—The result here attained seems to interfere seriously with the Beta-iron theory. The non-magnetic properties of manganese-steel and also its peculiar hardness (not "dead" hardness, like hardened carbon-steel) have been adduced as proofs that Beta-iron must exist. Manganese-steel, indeed, shows no recalescence. This, it is claimed, proves that just as ordinary iron is in the non-magnetic state above a bright red heat (750° C.), manganese-steel retains the iron in that form at ordinary temperatures.

Here, however, we have a manganese-steel which, after being treated in a cementation-furnace having a higher temperature than that required to produce recalescence, has become magnetic. Having been above the recalescence-point it must also have been at a temperature sufficiently high to change the soft into the hypothetical Beta-form of iron. In other words, it has been treated at such a temperature that a sample of carbon tool-steel heated at any period of the treatment which the manganese-bar underwent in the cementation-furnace would, if suddenly removed from the furnace and water-quenched, have become hardened. That is, the so-called Beta-form would have been retained. Unless some very strong reasons can be adduced, it would seem that the Beta-iron theory does not coincide with the facts now noticed.

It is also important by this experiment to have proved that the hardness of manganese-steel is independent of its magnetic condition, confirming Mr. Wingham's contention several years ago (*Journal of Iron and Steel Institute*, 1890, No. 1, p. 101) that the Beta-iron theory is inconsistent with the facts noticed in magnetizing hardened steel. He rightly asked: How could permanent magnetism in hardened carbon-steel be reconciled with the fact that such material was found so exceedingly suitable for the manufacture of permanent magnets if the iron present in that material was in the Beta-form, the latter being supposed to be non-magnetic? If hardened steel is a material in which non-magnetic Beta-iron is imprisoned, so to speak, how comes it that such a steel is, of all others, the most suitable medium

for articles requiring magnetic retentiveness? Mr. Wingham further added that to make the hypothesis more acceptable it would be necessary to say that "apparently hardened steel must contain some Alpha-iron." This, of course, is quite inconsistent with the facts known. The harder the steel the more pronounced are its qualities of magnetic retentiveness.

The writer would point out also that, conversely, wrought-iron, in which there is supposed to be no iron present in the non-magnetic or Beta-form, even if quenched from a high heat, ought to make a good permanent magnet, as all the iron present is supposed to be in the Alpha and magnetic state. It is certainly subject to magnetic influence, but otherwise it has just the opposite quality.

The writer cannot but think that if two pieces of wrought-iron were tested for magnetic retentiveness, one having been water-quenched from a high heat, the latter would be the superior—perhaps only slightly so, but sufficient to show that there had been some marked change, and that this was due to the effect of rapid cooling, causing an alteration in the structure, just as the same results, only in a much more marked manner, occur in carbon-steel. In other words, such change would be owing to an alteration in the form of crystallization, the causes of which we are beginning to understand better by means of the microscope.

Abel's and Ledebur's researches do not give any reasons, but rather the contrary, to believe that hardness is in any way owing to a hard form of iron. Other experiments by the writer, including those on silicon, aluminum, copper, chromium, tungsten, and other alloys, all prove that unless carbon be present no quenching hardness results. Manganese-steel has hitherto afforded a notable exception, though never equalling the hardness of carbon-steel.

The magnetic properties of manganese-steel have been very carefully investigated by Drs. Hopkinson, Bottomley, and Fleming, Profs. Barrett and Ewing, and many other leading scientists. This material has specially invited scientific investigation, owing to its peculiar presentation of iron, the most magnetic element known, entirely or practically deprived of its magnetic qualities.

As far back as 1773, Rinman noticed this, and in 1830 Mushet produced ferro-manganese which was non-magnetic, but such alloys were neither malleable nor ductile. The manganese-steel, when worked hot, can be reduced to the thinnest sections or drawn cold to fine wire (No. 32 B. W. G.). For this, however, great care is re-

quired, but ordinary gauges, to about No. 20 B. W. G., present no special difficulty.

It is surprising to find 14 per cent. manganese steel almost as inert to the highest magnetic forces as copper or other diamagnetic metals. Even in the most favorable samples its permanent magnetism is exceedingly small. To use a metallurgical simile, this quantity may be described as one would talk of the effect of .02 per cent. of manganese upon ordinary carbon-steel.

Prof. Ewing gives its permeability as 1.46 (the force ranged up to 16,000 C. G. S. units, and with this the magnetic induction rose to nearly 15,000 C. G. S. units, the ratio of induction to force being as thus given).

TABLE XVIII.

Material tested.	Experimenter.		
Manganese-steel.	Ewing.	Permeability, . . .	1.46
"	"	Magnetic susceptibility, .	.036
Soft wrought-iron.	"	. . . . .	280
Manganese steel.	Barrett.	Magnetization per gramme,	0.13 C. G. S. units.
Ordinary steel,	"	" "	40 to 60, even up to 100 units.

Thus the ratio of magnetization is as 1 to 3000 and up to 7000 in the best sample of manganese-steel in comparison with ordinary steel.

Prof. Barrett, the discoverer of recalescence, found that manganese-steel gave no "after-glow," and no magnetic tick or sound was heard, as when magnetizing and de-magnetizing iron, nickel, or cobalt. Nickel he found to lose its magnetic properties at 330° C. Iron is now well known to do so at about 750° C.

Electrical Resistance.—In America, where so much attention is paid to electrical developments, there should be a considerable use of manganese-steel for resistance-work.

Professor Barrett, Dr. Fleming, Mr. Mordey, of the Brush company, London, Dr. Hicks and others, have made careful tests of the electrical resistance of this steel, the results of which are summed up in Table XIX.

The well-known firm of English electrical engineers, Messrs. Willans & Robinson, of Thames Ditton, have used 1½ tons of manganese-steel for resistance-coils in connection with a special electrical installation.

TABLE XIX.

Material.	Experimenter.	Microhms per cubic centimetre.	Temperature co-efficient in degrees Centigrade.
Manganese-steel,	Fleming.	68.00	.....
Manganese-steel,	Barrett.	75.00	.135
Manganese-steel,	Hicks.	65.30	.129 .127
Iron,	Barrett.	9.80	.40
German silver,	Barrett.	21.17	.04
Nickel,	Barrett.	14.10	.40
		Copper unity.	
Copper,	Mordey.	1	.23
Soft iron,	Mordey.	5	.69
Brass,	Mordey.	6	.40
German silver,	Mordey.	8.80	.03
Platinoid,	Mordey.	20.00	.....
Arsenical copper,	Mordey.	27.00	.03
Manganese-steel, according to percentage of manganese.		37.00 to 48.00	.136 (Barrett). .10 (Willans).

THERMAL AND ELECTRICAL CONDUCTIVITY AND SPECIFIC HEAT OF MANGANESE-STEEL.

A paper on these interesting questions was read by Dr. A. Crichton Mitchell, before the Royal Society of Edinburgh on April 1st and July 1, 1889, and as the scientific results obtained there have great practical bearing and do not appear to have been mentioned in the technical papers, details may be of service here.

It has been found that manganese-steel requires very careful heat-treatment. In heating, ingots are very liable to crack unless most slowly and gradually warmed. In several ways this steel shows itself to be a bad conductor of heat.

'This difficulty is clearly indicated by Dr. Mitchell's experiments, which confirm the correctness of practical observations on this point. In order to carry out his experiments he had to prepare finished bars of considerable lengths. Owing to the hardness of the steel it may be readily imagined that this was not an easy matter, much skill and patience being necessary. The object was at last accomplished by grinding and drilling. The bars were 50½ inches and 20 inches long, respectively, each being 1⅛ inches square. In the bar for the former experiments eight holes were drilled for the insertion of carefully standardized thermometers, the first being 9 inches from one end, the others 12, 15, 18, 20, 24, 30 and 42 inches respectively from the same end. The holes were 1⅛ inches deep and $\frac{17}{64}$ inch in diameter. One hole of the same size as the above was drilled in the shorter bar,

which was fitted with screw-eyes at the ends with which to support it on bearings while being heated. Both bars were finally nickel plated.

The method of finding the conductivity was substantially that originally devised by Forbes, the only difference being that a shorter bar was used, and the cooling-bath was placed either at its cooler end or near its middle on the cooler side of the fifth thermometer. Full details of the exact methods adopted will be found in Professor Tait's paper on "Thermal and Electric Conductivity" (*Transactions of the Royal Society of Edinburgh*, vol. xxviii.), and Dr. Crichton Mitchell's paper "On the Thermal Conductivity of Iron, Copper, and German Silver" (*Trans. of the Royal Soc. of Edinburgh*, vol. xxviii.).

Of the eight holes drilled only five were used, viz, the first four separated by intervals of 3 inches, and the fourth and fifth by one of 6 inches. The cooling-bath through which a stream of water was kept steadily passing, was placed close to the fifth hole.

The method of finding the conductivity, and the manner in which the readings of the thermometers were reduced, and from them the curve of stationary temperature-excess constructed, are described in Dr. Mitchell's paper above mentioned.

The final results showed that the thermometric conductivity of manganese-steel is represented by the following numbers:

(1) From areas uncorrected for change in specific heat,

0°	100°	200°
.00211	.00246	.00281

(2) From areas corrected for change in specific heat,

.00219	.00272	.00325

For comparison between manganese-steel and a wrought-iron bar Dr. Mitchell states the following figures:

	0°	100°	200°
Manganese-steel, ...	.00219	.00272	.00325
Iron, ...	.0019	.01274	.01358

Thus it appears that manganese-steel at 100° is lowered to one-fifth and the rate of increase of conductivity with temperature is in manganese-steel little more than half the corresponding coefficient of iron. It can be easily understood why manganese-steel pokers used by several friends of the writer have been prized so highly.

Owing to the high electrical resistance of manganese-steel, it might

naturally have been expected that this low conductivity would follow, again confirming the similar qualities and effects of currents of heat and currents of electrical energy.

The specific-heat determinations were made with $1\frac{3}{8}$-inch cubes of wrought-iron and manganese-steel respectively.

Each was raised to a temperature of 300° C., and then, by means of a thermometer inserted in a mercury-filled hole previously drilled in each cube, the rates of cooling were carefully deduced. The specific heat of the iron cube was found to be 0.114, agreeing with previous experimenters, and that of the manganese-steel 0.124 or 1.087 times that of iron. Its rate of rise with temperature was the same as that of the iron.

Electrical Conductivity.—Prof. Barrett and M. H. Le Chatelier have made a careful series of experiments with this steel with respect to its expansion in wires 19 B. W. G. (0.96 mm. diameter) at temperatures from 0° C. to 1000° C. The results showed the following coefficients:

TABLE XX.—*Coefficients of Expansion.*

Manganese-steel, Barrett,	.000015	1° to 100° C.
Ordinary steel, Barrett,	.0000117	
Manganese-steel, Le Chatelier,	.0000245	1° to 1000° C.
Ordinary steel, Le Chatelier,	.000015	

Contraction of Manganese-Steel.—In view of the very exact records of Dr. Mitchell and others, it is easy to understand that the contraction of manganese steel from the fluid state must be serious, and that, if the care and ingenuity of the steel-founder are necessary to avoid contraction-cracks in ordinary steel, this is still more the case with manganese-steel.

The following comparisons of contraction were made at the Hadfield Steel Foundry Company's works. Bars 2 inches square, with flanges, and projecting at each end about $12\frac{1}{4}$ inches beyond the latter, were cast of various qualities of steel, the results being as follows:

TABLE XXI.

Material.	Distance between flanges. Before casting. Inches.	After casting. Inches.	Contraction on 12 inches.	Contraction. per cent.
Medium cast-steel, 0.50 per cent. C,	12.256	12.0215	.2345	1.91
Medium cast-steel, 0.60 per cent. C,	12.256	1 .9326	.2734	2.23
Manganese-steel as cast,	12.256	11.8026	.4534	3.60
Manganese-steel, water-quenched,	12.256	11.9045	.3515	2.80

The cast manganese-steel, therefore, showed the high rate of 3.60 per cent. contraction against about 2.00 per cent. for carbon cast-steel. The usual pattern allowance by steel-founders is $\frac{1}{4}$ to $\frac{5}{16}$ inch per foot, or about 2 per cent. (which the above table confirms) so that manganese-steel is considerably higher. But the curious point is that, after water-toughening, the manganese-steel has expanded considerably in the sample. The details of this test may not be exactly accurate, as it is possible the bar may have become bent during the heating for the water-quenching process. Still there is clear evidence that comparatively a considerable change has occurred under this treatment. This has been borne out by some independent tests relating to specific gravity made for the writer by Mr. David Kirkaldy, of the Testing Laboratory, London, who found that manganese-steel varied in its specific gravity according to the state in which it existed.

TABLE XXII.

Experimenter.	Material.	Specific Gravity.
Kirkaldy,	Manganese-steel as forged,	7.8674
	Manganese-steel, air-toughened or annealed,	7.8630
	Manganese-steel, water-toughened,	7.8615
Barrett,	Manganese wire, 19 B. W. G.,	7.81
Hadfield,	Manganese wire, 19 B. W. G.,	7.863
Arnold,	Pure iron (99.8 per cent. Fe.),	7.8630

This being an interesting point, it may be well to give Mr. Metcalf's results of very carefully taken specific gravities of carbon-steel of various percentages and quenched at different heats. Four samples only are selected; but full details of 12 tests will be found in Mr. Metcalf's admirable contribution to the discussion on Mr. Cunningham's paper, "Hardening Structural Steel," read before the American Society of Civil Engineers, June 10, 1892.

TABLE XXIII.

Sample No.	Carbon per cent.	Specific gravity of ingots.	Rolled bar.	Bar quenched black hot.	Bar quenched at scintillating heat.
3	.52	7.841	7.844	7.831	7.818
6	.84	7.824	7.829	7.812	7.789
10	1.00	7.807	7.826	7.812	7.744
Arnold's pure iron, 99.8 per cent. Fe	.07	.....	7.863	.....	.....

The difference between the rolled and the water-quenched bars of carbon-steel (Table XXIII.) is considerable. In the manganese-

steel, Table XXII., the difference is much smaller, but still sufficient to be detected. If worked out on cubes weighing, say a ton, and the difference in size allowed for expansion between forged and forged-water-quenched, the weight would not be altered more than two pounds.

Hardness.—As it is very important when comparing hardness to have some more exact standard than filing or chipping, the writer appends a table which may be of service. Most of the tests have

TABLE XXIV.

Description of sample.	Mark.	Condition.	Analysis.					Scale of hardness by Turner's sclerometer.
			C.	Si.	Mn.	Al.	Cr.	
Manganese-steel	783	As forged.	.74	.50	12.05	.....	.....	60
" "	931	"	.55	.39	7.10	.....	.....	80
Silicon-steel	A	"	.14	.24	.14	.....	.....	20
"	B	"	.18	.79	.21	.....	.....	20
"	E	"	.20	2.67	.25	.....	.....	26
"	G	"	.25	4.49	.36	.....	.....	33
Aluminum-steel	1167	"	.22	.09	.07	.15	.....	20
" "	1167 D	"	.17	.19	.18	.72	.....	20
" "	1167 H	"	.24	.18	.32	.21	.....	20
Chromium-steel	1176 A	"	.07	.07	.11	.....	.22	22
" "	1176 E	"	.12	.08	.18	.....	.84	24
" "	1176 H	"	.39	.14	.25	.....	2.54	24
" "	1176 J	"	.77	.50	.61	.....	5.44	43
Lead								1
Copper								8
Rolled-platinum								14
Softest iron								15
Mild steel								21
Good razor-steel								60
American chilled car-wheel								66
Very hard white iron								72

been made by Prof. Turner, of the Mason College, Birmingham, with his sclerometer, an apparatus which has also been used with satisfactory results in America by Mr. W. J. Keep, of Detroit.

THE GENESIS OF ORE-DEPOSITS.

BY F. POŠEPNÝ, VIENNA, AUSTRIA.*

(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

CONTENTS.

INTRODUCTION.

PART I.—GENERAL FACTS AND THEORIES.

PAGE

1. *Systems of Classification Employed Hitherto,* . . . 199
2. *Standpoint and View of the Present Paper,* . . . 205
3. *The Xenogenites in General,* 207
4. *The Subterranean Water-Circulation,* 212

A. The Vadose Underground Circulation, . . . 213
Filling of Open Spaces Formed by Vadose Circulation, . . 217

B. The Deep Underground Circulation, ... 220
Ascending Waters Encountered in Mines, ... 222
Related Phenomena near the Surface, ... 225
Mineral Springs at the Surface, ... 230
Chemical Constitution of Mineral Waters, ... 232
Minute Metallic Admixtures in Mineral Waters, . . . 238
Alterations Produced by Mineral Springs, ... 240
Structural Features of the Deposits of Mineral Springs, . . 244

5. *Origin of Ore-Deposits in the Deep Region,* . . . 247
Manner of Filling of Open Spaces in General, . . . 254

PART II.—EXAMPLES OF CLASSES OF DEPOSITS.

1. *Ore-Deposits in Spaces of Discission,* 264
General Features and Illustrations.
a. Ore-Veins in Stratified Rocks, ... 269
Clausthal, 269; Andreasberg, 270.
b. Ore-veins in the Neighborhood of Eruptive Masses, 271
The Erzgebirge, 271; Przibram, 272.
c. Ore-Veins Wholly Within Large Eruptive Formations, 274
Hungary, 274; Dacian Gold-field, 275; Verespatak, 276; Vulkoj, 276; Comstock lode, 278.

* Translated by the Secretary.

PAGE

2. *Ore-Deposits in Soluble Rocks*, ... 283
Fillings of Spaces of Dissolution and Metasomatic Deposits.
Rodna, 283; Offenbánya, 285; Rézbánya, 286; Raibl, 289; North of England, 292; Leadville, Colo., 293; Red Mountain, Colo., : 96; Utah, 297; Nevada, 297; Deposits in Structural Plateaux, 301: Vallé and Mine la Motte, Mo., 302, 303; Wisconsin, 303.

3. *Metamorphous Deposits*, ... 304
General Features.

a. Ores in Distinctly Stratified Rocks, ... 306
Deposition of Ores from Sea-Water, 306; from Fresh Water, 308; the Kupferschiefer of Mansfeld, 309; of Thuringia and Bohemia, 309; of Westphalia, 310; the Copper-Sandstones of Bohemia, 312; of St. Avold, 312; Lead-Deposit of Mechernich, 313; Freihung, 314; Silver Reef, Utah, 315; Copper-Deposits of New Mexico and Arizona, 316; Boleo, Lower Cal., 317.

b. Metasomatic Deposits in Soluble Rocks, . . . 318
Calamine-Deposits, 318; Laurium, 319; *Bohneisenerze* of Alsace, 321; Cumberland, 321; Wochein, Carniola, 321.

c. Deposits in Crystalline Schists and Eruptive Rocks, 321
Taberg, Sweden, 322; Cornwall, 323; Scandinavia, 324; Åmmeberg, 325; Prettau in Tyrol, 327; Lake Superior, 328; Sudbury, Can., 329.

4. *Hysteromorphous Deposits*, ... 331

a. Chemical effects, ... 331
Limonite near Rio Tinto, Spain, ... 332

b. Mechanical effects, ... 335
Verchoviky, Surface-Deposits *in situ*, 335; Theory of the Sinking of Heavier Constituents, 336; Stream-detritus, 337; Marine detritus, 339: Kackar District, Ural Mountains, 339; Platinum-placers, 340: Tin-placers, 341.

c. Hysteromorphs of the Older Geological Formations, . 342
Deadwood, Dakota, 343; Australasia, 344; South Africa, 344: Bohemia, 345.

INTRODUCTION.

ALL serious investigators of this problem have recognized its complex character, and the difficulty of solving it definitively in the present state of our knowledge. Single and simple occurrences are at present clearly understood; but the more complicated phenomena give rise to discordant and often totally contradictory views, showing that we are still far from the truth upon this subject. The study of it has been the labor of my life; yet I must confess that the little I have here and there accomplished bears no proportion to the great range of the inquiry. I collect, nevertheless, in this paper, some of the personal views to which I have been led, chiefly in order that they may be submitted for consideration and discussion to my American colleagues.

Looking upon a single, somewhat complicated ore-deposit, we must confess that a superficial, tourist's examination of it could not give satisfactory results. Yet the literature of this subject refers us to such materials chiefly. Even treatises based upon the profound studies of years do not exhaust the subject; for they are affected by the existing stage of development of the auxiliary sciences, by the existing degree of exploration and exposure of the deposits described, and by the personal views of their authors.

Mining, indeed, constantly furnishes fresh evidences in new openings, but it destroys the old at the same time; and if these are not preserved for science before it is too late, they are lost forever. The whole mining industry is in its nature transitory; but the nation, which intrusts to the miner, upon certain conditions, the extraction of its mineral wealth, has a right to demand that the knowledge thus gained at the cost of a part of the national resources shall not be lost to science.

PART I.

GENERAL FACTS AND THEORIES.

1. Systems of Classification Employed Hitherto.

Studies of individual deposits naturally involve speculations concerning their genesis, and many such monographs contain valuable data, which, for the more thoroughly examined mining districts, are so well established and so comprehensive as to invite a systematic arrangement and a genetic explanation. At first, only the form of the ore-deposit was considered in such classifications; afterwards the barren surrounding medium was included. From this standpoint, unfortunately still taken by some purely empirical experts, the earth's crust is primarily divided into ore-bearing and barren rocks.

It was especially the *true veins*, at one time the principal objects of mining, which gave rise to speculations and discussions, having now only a historic interest.* A. Werner was the first to frame a scientific theory. He distinguished between ore-deposits contemporaneous in origin with the enclosing rocks and those of subsequent

* The period 1556 to 1791, that is, from G. Agricola to A. G. Werner, is an illustration. See also *Die Besonderen Lagerstätten der Mineralien*, by J. Waldauf von Waldenstein, Vienna, 1824, p. 164, etc.; *Die Lehre von den Erzlagerstätten*, by B. von Cotta, 2d ed., Freiberg, 1859, p. 85, and the English translation by F. Prime; and J. A. Phillip's *Treatise on Ore-Deposits*, London, 1884, p. 74, etc.

formation, and proved once for all that veins are fissures filled with ore, thus furnishing the most important characteristic for the recognition of primary and secondary formations. As to the manner in which fissures have been filled, Werner's theory, based upon a comparatively limited field of observation, has, like many of his neptunistic views, failed to maintain itself; and this question remains still without a final answer.

Curiously enough, many systematizers reproached Werner for having introduced into his system a genetic principle, which they sought to eliminate, confining themselves to the form of deposit as a guide. Thus Waldenstein (*op. cit.*, p. 5) distinguished (*a*) tabular deposits (beds and veins); (*b*) stock-deposits, flat-lying or steeply inclined; and (*c*) scattered masses, such as nests and pockets.

Even Cotta, otherwise an earnest advocate of geological principles, classified ore-deposits according to their form and kind as beds, veins and masses, adding a new and somewhat indefinite group of "impregnations." J. Grimm* also followed in the main the old principles of classification; included in his system the eruptive ore-breccias which he had personally examined and the tabular segregations of ore, and pronounced not only ore-beds (*Erzlager*), but also certain bed-masses (*Lagerstöcke*) to be sedimentary formations. Dr. A. von Groddeck† followed genetic principles already acquiring predominance. He distinguished: (*a*) original deposits, and (*b*) deposits of débris. The former he subdivided into (1) those formed contemporaneously with the country-rock, and stratified (ore-beds, segregated beds, etc.) or massive; (2) those formed later (cavity-fillings, veins, cave-deposits, metamorphic deposits). He pronounced ore-beds (*Erzlager*) to be sedimentary, and included in his system the cave-deposits and metamorphic deposits without describing their occurrence in detail. He declared that his system, like all others, had only the purpose of arranging the material of observation conveniently for comprehensive study, and that the manifold products of nature could not be forced into a system of classification.

Groddeck's description of the series of forms of deposits is highly original. He presents a number of types, mainly characterized by the varying material of the deposits and its manifold combinations and transitions. Evidently there was before him the ideal of combining in a systematic representation the different standpoints from which the subject was to be viewed. At least, if I correctly under-

* *Die Lagerstätten der nutzbaren Mineralien*, Prague, 1869.

† *Die Lehre von den Lagerstätten der Erze*, Leipzig, 1879.

stood his personal, oral communication of his views, he hoped to represent one standpoint by abscissæ and the other by ordinates, so that the intersection would determine the type of the deposit. This is true enough; but it presupposes an exhaustive knowledge from both standpoints, which we unfortunately do not possess. My way of looking at the subject was, as appears from his expressions in a later publication, incomprehensible to him.* It seemed to him a sort of heresy to doubt the contemporaneous deposition of the ore of the Mansfeld copper-schists with the rock, although I assured him that this doubt need only continue until the chemical and physical possibility of such a deposition should be shown.

Groddeck's system comprises, it is true, the metamorphic deposits, but without special definition or illustrative examples. In answer to a criticism of A. Stelzner's† on this point, he replies that he has included in this class those deposits also which have been formed through alteration of the rock-material by the process which Stelzner had proposed to call metasomasis, but that the ore-bearing masses thus originated cannot be regarded as separate deposits, because they are only incidental phenomena of the filling of cavities. In other words, he grants but subordinate rank to one of the clearest and most important genetic aids to classification, furnished by the occurrence of rocks transformed into ore. After conceding that deposits of débris should probably be included among stratified deposits, he restricts his system to four chief classes: 1. Stratified or sedimentary deposits; 2. Massive or eruptive deposits; 3. Cavity-fillings; 4. Metamorphic and metasomatic deposits. This brings him essentially nearer to my view, which groups the first two classes together, as contemporaneous with the country-rock in origin, with the reservation, however, that the contemporaneity indicated by the stratigraphy should be verified by other evidence.

While the work of J. Grimm comprises all useful deposits, that of Groddeck is confined to ore-deposits, although it would be practicable to classify salt, coal and other beds under his system.

In England and America the subject has been variously viewed, considerations of practice being predominant, and stratification being regarded as the specially decisive factor. This conception appears

* "Bemerkungen zur Classifikation der Erzlagerstätten," *Oesterr. Zeitschr.*, 1885; *Rev. Univ. des Mines*, 1886, xix; *Gornoj Jour.*, 1886, iii., p. 430. "Unverständlich ist es mir, dass Pošepný, der sich so grosse Verdienste um die Kenntnisse der Erzlagerstätten erworben hat, das Vorkommen sedimentärer Erze ganz ignorirt," etc.

† Cited in *Das neue Jahrb. f. Mineralogie*, 1880, ii., *Referate*, p. 50.

first, so far as I know, in the writings of J. D. Whitney,* who divides mineral deposits primarily into (1) superficial, (2) stratified and (3) unstratified. The stratified deposits are divided into (*a*) those in which the valuable mineral constitutes the mass of a bed, (*b*) those in which it is disseminated through sedimentary beds, and (*c*) those originally deposited from aqueous solution, but since metamorphosed. The unstratified deposits are again divided as irregular [subdivided into (*a*) masses of eruptive origin (*b*) disseminated in eruptive rocks; (*c*) stock-work deposits; (*d*) contact-deposits; (*e*) fahlbands] and regular [subdivided as (*f*) segregated veins; (*g*) gash-veins; (*h*) true or fissure-veins].

We find here an explanation of the term "gash-veins," unfamiliar in Europe. Whitney says (*op. cit.* p. 225):

"Segregated veins, which are peculiar to the altered crystalline, stratified or metamorphic rocks, are usually parallel with the stratification and not to be depended on in depth. Gash-veins may cross the formation at any angle, but are peculiar to the unaltered sedimentary rocks. True veins are aggregations of mineral matter, accompanied by metalliferous ores, within a crevice or fissure, which had its origin in some deep-seated cause, and which may be presumed to extend for an indefinite distance downwards."

Somewhat different is the classification of R. Pumpelly,† who distinguishes: I. *Surface-deposits* [(1) residuary, (2) stream-, (3) lake- and bog-deposits]. II. *Forms due to the texture of the enclosing rock or to its mineral constitution, or to both* [(1) disseminated concentrations, further subdivided as (*a*) impregnations and (*b*) fahlbands; (2) aggregated concentrations, comprising (*a*) lenticular, (*b*) irregular masses or "stocks," (*c*) reticulated veins or "stock-works," (*d*) contact-deposits]. III. *Forms due chiefly to pre-existing cavities or open fissures* [(1) cave-deposits; (2) gash-veins; (3) fissure-veins].

Dr. R. W. Raymond,‡ who followed, in the main, the classification of Lottner,§ distinguished: I. *Superficial Deposits* [(1) Deposits of débris (placers); (2) surface-formations in place (bog-ore, etc.)] II. *Inclosed deposits* [(1) sheet-formed or tabular, divided into (*a*)

* *Report of a Geological Survey of the Upper Mississippi Lead Region*, Albany, 1862, p. 224, and *The Metallic Wealth of the United States*, Philadelphia, 1854, p. 34.

† Not possessing the original work, I quote from the monograph of S. F. Emmons, *Geology and Mining Industry of Leadville*, Washington, 1886, p. 373.

‡ *Report of the Commissioner of Mining Statistics*, Washington, 1870, and the reprint, *Mines and Mining of the Rocky Mountains*, New York, 1871, p. 448.

§ *Bergbaukunde*, Berlin, 1869.

lodes or veins, and (*b*) beds and seams; (2) mass-deposits, divided into (*a*) masses, and (*b*) impregnations, etc.; and (3) other irregular deposits, such as (*a*) pockets distributed in large deposits, (*b*) isolated segregations, gash-veins, etc.].

Prof. J. S. Newberry* adheres mainly to the classification of J. D. Whitney, with some new matter of his own, the value of which has been justly estimated by Raymond.†

An analogous line of thought is followed by J. A. Phillips.‡ He declares that a careful study of the origin, structure, and composition of ore-deposits, appears to justify their division into the following groups: 1. *Superficial* [(*a*) formed by the mechanical action of waters, (*b*) resulting from chemical action]; 2. *Stratified* [(*a*) constituting the bulk of metalliferous beds formed by precipitation from aqueous solutions, (*b*) beds originally deposited from solution, but subsequently altered by metamorphism, (*c*) ores disseminated through sedimentary beds in which they have been chemically deposited]; (3) *Unstratified* [(*a*) true veins, (*b*) segregated veins, (*c*) gash veins, (*d*) impregnations, (*e*) stock-works, (*f*) fahlbands, (*g*) contact-deposits, (*h*) chambers or pockets].

In France, comparatively little has been done in framing such systems, higher importance being attached to the synthesis of the minerals, the explanation by experiment of geological processes, and the attempt to confirm by the study of mineral-deposits in other countries the theories thus supported. Observations have been made in many cases, not to furnish material for new conclusions, but to prove the truth of existing theories, as, for instance, Elie de Beaumont's theory of "pentagonal symmetry" in the relation between mineral veins and the courses of mountain ranges, etc.

In recent times, the chemical standpoint has become dominant with the French school, and in the treatise of De Launay,§ which has just appeared, the attempt is, in fact, made to base a system of ore-deposits upon a purely chemical view of the subject. He distinguishes: 1, *Gîtes d'inclusions* (ores as primitive constituents of eruptive rocks); 2, *Gîtes filoniens* (containing ores deposited, no

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* "The Origin and Classification of Ore-Deposits," *School of Mines Quarterly*, New York, March, 1880; also, *Eng. and Min. Journal*, New York, vol. xxix., 1880, pp. 421 and 437.

† *Eng. and Min. Jour.*, vol. xxx., 1880, p. 1.

‡ "A Treatise on Ore-Deposits, London, 1884, p. 3.

§ "Formation des Gîtes Metallifères," *Encyclopédie Scientifique des Aide-memoire, publiée sous la direction de M. Léauté*, Paris, 1893.

matter how, in pre-existing cavities in the rocks); and, 3, *Gîtes sédimentaires* (where metallic substances have been laid down, either as sediments or as precipitates, in marine- or fresh-water basins). In another place I will say something of this view, which, in some respects, corresponds with my own.

It is evident from the foregoing mere enumeration of the names of groups and classes of the several systems that, as a general rule, every new observation, considered important by the observer, has been added to the established traditional conception, which, however, was primarily based upon distinctions of form and kind, to which genetic principles, if recognized at all, were secondary. I may refer, in illustration, to the class of "pipe-veins," and the exhaustive paper of Dr. Raymond* demolishing it. I myself once thought a new group to be warranted by conclusive observations, namely, *typhonic* deposits,† in which the ores occur cementing together the fragments of a brecciated mass. But I soon became convinced by the observation of other occurrences, equally difficult to fit into the existing system, that the whole system must be transformed before it could assimilate, without destruction to itself, the new facts observed in the course of time.

But a stable and complete system can only be framed, when all the controlling facts—in other words, all the ore-deposits—are accurately known. This is not likely ever to be the case. New observations are constantly made in mining, which, moreover, often obliterates the old ones, so that they cannot be verified and compared.

It is, however, absolutely necessary, in a field so complicated as that of ore-deposits, to have some general understanding, some sort of system, comprising what is known. And evidently, in framing a system, the characters of form, being the most obvious and the most familiar to the miner, would be naturally emphasized, while genetic characters were left in the background. But this ought not to check genetic investigation, or the advancing recognition of real relations. A genetic system must, indeed, involve hypotheses, and may not, for a while, be practically useful; but in time it will, like every other cultivated branch of geology, assume more permanent forms.

At the Przibram Mining Academy there was established, in 1879,

* *Trans. A. I. M. E.*, vi., 393.

† "Ueber typhonische Gesteinsmassen," *Verh. d. k. k. geol. Reichsanst*, 1871, p. 94.

a new chair of "The Geology of Mineral Deposits," which I occupied for about ten years. As the title indicates, it was not merely intended for instruction in the usual "science of mineral deposits," and not as a geological course, appended to the technical course in mining, as might be inferred from a title like "*Montangeologie*," or "Mining Geology." The leading subject in view was the genesis of the useful mineral deposits. In the present paper I purpose to give a brief statement of the substance of my lectures, which, apart from a few extracts, have never been published.

2. Standpoint and View of the Present Paper.

The principal genetic distinction is doubtless between deposits contemporaneous with the country-rock, and those subsequently formed in it.

The earth's crust consists of rock-elements, chiefly individualized as mineral species. Two or three dozen of them—the rock-forming minerals—constitute by far the larger part of the solid earth as known to us. The remainder, much greater in number and variety, ornament our mineral cabinets, but form an insignificant portion of the rocks. The greater part of this group is made up of the legion of minerals occurring in ore-deposits; and most of these have undoubtedly had a secondary origin in the rocks—for instance, all the cavity-fillings, which of course could only be deposited after the rocks were formed. The secondary origin of some minerals which do not occur in cavity-fillings is less evident. But they occur sometimes in company with those which clearly have this character; so that we may consider these numerous minerals, occurring in comparatively small quantities, as secondary.

We have two main groups of mineral aggregates: that of the *rocks*, and that which we will call comprehensively *the mineral deposits*. The minerals of the first group belong to it as native and original; those of the second are foreigners to the rocks in which they occur. The two groups may therefore be designated (from ἴδιος, one's own, and ξένος, strange) as *Idiogenous* and *Xenogenous* respectively.

It is not necessary here to consider the various origins of rocks, since we take as our starting-point the rocks already formed. The clearly sedimentary rocks consist of the débris of older formations—idiogenous as well as xenogenous; and we must distinguish in them, besides mechanical sediments, chemical precipitates and organic products.

The sediment of a basin is the detritus carried into it from the land and deposited in the form of a flat wide cone. Successive conical envelopes should therefore strictly be the form of such sedimentary beds, though frequently they present apparently level parallel strata. The deposition of a precipitate, on the other hand, takes place throughout the liquid in the basin, and its form more completely represents the ideal *stratum*. In both sediments and precipitates, we find sometimes, besides organic remains, finely divided organic substances, forming the bituminous portions of the rocks. But the great masses of vegetable matter forming the coal-beds were, according to the most widely held opinion, deposited in swampy bottoms, and are therefore neither sediments nor precipitates. Several coal-beds, one above another, indicate a slow sinking of the basin, and its periodical filling-up with detritus from the rivers to such an extent that vegetation could again take root.

A coal-basin with several beds becomes on this view the measure of the sinking which is doubtless the cause of every large basin, but which only becomes strikingly evident when the basin contains coal-seams.

The foregoing points are mentioned because they indicate original discordances in stratification among the sedimentary layers themselves, and between these and the precipitates and organic formations.

If we find in the midst of these formations ores lying exactly between two strata, this relation is not conclusive proof of their sedimentary or precipitative origin. This must be proved in every given case; for in the present state of our knowledge we cannot understand how the metallic sulphides so characteristic of ore-deposits could be formed in that way.

As to the eruptive rocks, we do not know what they once were, as we study them only from the moment of cooling. But we observe at once that iron—a metal widely distributed in ore-deposits and in nature generally, occurs primitive in these rocks, in the form of magnetite, a mineral of striking metallic appearance.

This idiogenite of the eruptive rocks can be detected without chemical aid; but with such aid we find traces of other metals besides iron; and this leads us to surmise that the eruptives have brought a whole series of heavy metals up from the "barysphere" into our "lithosphere," and that it looks as if the metals of our ore-deposits originally belonged to the barysphere. This surmise De Launay regards as already proved. He derives, as it were, *a priori*, all the

heavy metals of our ore-deposits from the eruptive rocks, and erects upon this hypothesis an entire system.

3. The Xenogenites in General.

With relation to the xenogenites or mineral deposits, the first question concerns the space which every secondary mineral or mineral-aggregate requires to establish its existence. It must either have found this space waiting for it, or it must have made room by driving out an original mineral.

Although we shall chiefly consider cavities formed in rocks after the formation of the rocks themselves, we must not forget that some may have been primitive in the rocks. We know that in substances of the greatest apparent density small cavities or pores must exist, since we can, for instance, by adequate pressure, force quicksilver through them. Moreover, we encounter in the eruptive rocks larger cavities, suited to receive considerable mineral-aggregates—the so-called blow-holes. These phenomena must certainly be considered, although the cavities of secondary origin will first be the subject of attention.

With regard to the filling, I observe, first, that the mineral deposits upon the walls of cavities, from liquids circulating within them, usually have a characteristic structure, for which I propose the name "crustification," as a companion to "stratification." (Single crusts were formerly called mineral shells or scales; and Groddeck introduced the word "crust," which is comprehensible in most languages.)

Most frequently mineral crusts occur concentrically in regular succession, and fill the whole cavity (except the central druse), thus forming a symmetrical crustification. They cover, however, not only the cavity-walls, but the surface of every foreign body in the cavity, thus forming crusted kernels which greatly complicate the phenomenon. We shall see, however, that a geode-cavity serves much better than a fissure-cavity to explain the relations of crustification, and that the crusted kernels will give us no trouble in that regard.

Sometimes mineral crusts have undergone a secondary alteration (carbonates are replaced with silica, etc.). The crustification is thus made less distinct, or is even obliterated. As a general rule, however, *crustification is a characteristic feature of cavity-filling.*

The cavities are formed either by mechanical or by chemical forces; and these two classes must be sharply distinguished, in view of the

important rôle of each. The former may be the effect of exterior and foreign forces, or of such as are interior, residing in the rock itself. Formerly I called such spaces (with reference mainly to the accompanying fault-phenomena) "Spaces of Dislocation;" but I believe the term "Spaces of Discission" (from *scindere*, to tear apart) would be more suitable. The latter class I formerly called "Spaces of Corrosion" (with reference to the effect of the leaching and attacking liquids); but I would now substitute the more self-explanatory name "Spaces of Dissolution."

Spaces of dissolution naturally occur in soluble rocks, especially limestone, and show, with wonderful clearness, the irregular course often followed by underground waters. At and near the surface, we often find the cavity-formations at the contact of soluble with insoluble rocks; and we may infer that this relation affects also the subterranean circulation. Solution seldom extends to the whole mass of the soluble rock. Usually it affects a part only, in which it forms more or less irregular chains of cavities, sometimes so large that pieces of roof fall in, and thus spaces of discission are locally produced. A cavity filled with secondary mineral, however irregular its form may be, and even though it cuts across the stratification, usually shows a predominant course, which we are thus led to recognize as the channel of circulation of the liquid to which we owe the mineral deposit.

As I shall show later, we must assume that the liquid which formed the space of dissolution also performed the filling; in fact, that both processes were almost contemporaneous. Nevertheless, they must not be confounded with the metamorphic processes where the idiogenite is expelled, atom by atom, by the xenogenite; for the deposits in spaces of dissolution show always a distinct crustification, and hence every single crust, at least, must have found free space waiting for it.

Concerning the origin of spaces of discission, so much has been written that it cannot even be stated in abstract here. Two groups of these are distinguished. Those of the first group do not extend beyond one rock, and the force which produced them probably has its seat in that rock. In the eruptives, they are usually deemed fissures of contraction; in limestones and dolomites, J. D. Whitney called them gash-veins.

The cavities of the second group extend out of one rock into another. The force which produced them resided outside of the formation. Considerable movements of one wall along the other

are often evident, whence the common name, "fissures of dislocation."

In a paper upon this subject*, about twenty years ago, I attempted to show that every fissure, in whatever material, must properly be a fissure of dislocation; that the tendency to dislocation (namely, an unequal tension in the rock), precedes the formation of fissures; and that whenever the condition of the rock permits, a dislocation of the fissure-walls can be always traced, even in fissures of contraction.

As to the filling of spaces of discission, it must not be supposed that they represent throughout their entire length open spaces of uniform width. The original fissure was sometimes closed, wholly or partially, by the detritus originating in the friction of the walls, or by the movement or "swelling" of the country-rock, or by other causes. Only the places remaining open would permit an active circulation of solutions and a regular deposition from them. At points obstructed there would be no circulation, or a very sluggish one. When high pressure was present, and the rock contained interstices, the liquid doubtless penetrated from the fissure into the rock, impregnating it with mineral; or a soluble rock was attacked, and spaces of dissolution were formed, to be filled in like manner as the fissure itself.

This explains the fact that, on the same vein-plane, rich deposits alternate with poor or barren spots, and that the miner, seeking a bonanza, persistently follows the barren traces of the vein, according to a well-known, fundamental law of prospecting.

From the genetic standpoint, the richer portions are interesting as sometimes occupying more or less regular belts in the vein-plane, called "channels," "shoots," "chimneys," etc. These names evidently designate the main channels through which the mineral solutions passed; and the occurrence of such forms in most kinds of deposits tends to prove that, notwithstanding other differences, they were all formed in a similar way.

The *primitive* rock-cavities (pores and blow-holes) may also be filled with secondary minerals. In the former, there results a finely disseminated mineral substance, constituting such a deposit as Cotta denominated *impregnation*. Blow-holes are very often filled with minerals of the quartz family (opal, chalcedony, etc.), and we are often able to infer from the structure of such geodes the process by which they were filled.

* "Geol. Betrachtungen über die Gangspalten," *Jahrb. d. k. k. Bergakademien*, xxii., Vienna, 1874.

Where the mineral solutions found no cavity already prepared, they must have conquered the necessary place by expelling a corresponding part of the original material. When one mineral individual was replaced by another, as in cases of pseudomorphs, the nature of the process can often be inferred from a comparison of the composition of the two; and the laws thus discovered may frequently be applied to the problems of the origin of mineral aggregates. Many phenomena, however, even in the formation of pseudomorphs, are hard to explain,—the fact, for instance, that in some minerals the change commences within the mass and progresses outward, etc.

Where the original material was expelled, there must have been first an access for the liquids which began and executed this effect. Such may be furnished by original minute rock-cavities, or by secondary cavities.

The original substance of the greater part of the pseudomorphs known to us was composed of soluble minerals, such as carbonates, sulphates, and chlorides, which also occur as the elements of rocks. Hence it may be inferred that metamorphous or metasomatic deposits will be especially frequent in soluble rocks like limestone, dolomite, etc., and that we may also expect such deposits to occur frequently in company with those which fill spaces of dissolution.

Pseudomorphs show us one substance in the crystal-form of another. This indication is lacking for the recognition of metasomatic deposits; yet sometimes the original rock was characterized by peculiar structure, such as lamination or jointing—as, for instance, the cellular structure of the *Rauchwacke* (*Cargneule*), which is reproduced in the cellular calamine which has replaced it. Moreover, the original rock may have contained fossils, which have been replaced, with the rest, by the new mineral, retaining their form; for instance, the bivalves and mollusks of the Bleiberg limestone in Carinthia and at Wiesloch in Baden, reproduced in galena and calamine; the brachiopods of the Silurian iron-ores of central Bohemia, etc.

Most important for the study of the process are transitional forms between the earlier and the later material; for instance, coatings of the latter upon kernels of the former, such as limonite upon siderite or ankerite; and likewise important is the occurrence of regular pseudomorphs, replacing one element in a heterogeneous rock, like those of cassiterite after feldspar in the granite of Cornwall.

After the expulsion, atom by atom, of the original material, the resulting deposit must be massive, showing no crustification.

Frequently, however, there are only negative indications of the metamorphosis. It can be seen merely that the deposit is not an original rock; that it has not been deposited in pre-existing primitive or secondary cavities; and hence, that it must have been formed by replacement.

In general, two kinds of metamorphous deposits may be distinguished. In the first, the new material has replaced the more soluble ingredients of a heterogeneous rock, and the result resembles the description of an impregnation, in which the new material occupies the original interstices of the rock. In the second, a part or the whole of a homogeneous rock has suffered metamorphosis, and the deposit will bear a certain resemblance to filled cavities of dissolution.

As I have shown above, and will illustrate further on with some examples, we may thus establish certain types of deposits entirely without reference to form. Some of these may coincide with groups in earlier systems, but others appear together in one and the same group. This seems at first not to favor the practical usefulness of the above principles, but, as I have said, we do not yet know enough to frame a final system. That must be the aim of future studies, and it is obvious that our purely genetical factors will be more helpful than the arbitrary characters based upon the exterior form of deposits. We distinguish, then, *Idiogenites*, or deposits contemporaneous in origin with the rock, from *Xenogenites*, the deposits of later origin, including not merely those of ores, but mineral deposits in general; and to these we may add, in harmony with some older systems, the deposits of débris as a third class, *Hysterogenites*, or latest formations.

The *Xenogenites* we divide into such as penetrated pre-existing cavities (filling primitive cavities, spaces of discission, or spaces of dissolution), and the metamorphous or metasomatic deposits, which made room for themselves by the expulsion of an earlier material.

The form of all these deposits is not fixed, but depends upon various geological relations of the country-rock. The mention, under former systems, of regular forms of deposit, contemplated rather the ideal of the system itself. In reality, the ore-bodies in "veins" and "beds" are irregular, and form masses for which the most various names exist in all countries.

We must now speak more particularly concerning the method of formation of the different deposits. Probably no one doubts at the present day that they are predominantly the result of humid processes of solution and deposition. But such generalities are not enough. The processes alleged must be put upon the basis of actual causes, still operative, and capable of being proposed and discussed in explanation of geological phenomena. It is, therefore, necessary to introduce, at this point, the theoretical chapter which follows.

4. The Subterranean Water-Circulation.

In treating of the genesis of mineral deposits, this department cannot well be so lightly handled as it is in most text-books of general geology. Prof. A. Daubrée, in an authoritative discussion of the subject,* ascribes the mineral deposits, among other effects, directly to the liquids circulating underground. It is my desire, with the aid of personal observations incidental to my continuous study of such deposits, to present a somewhat closer view than that of Prof. Daubrée.

Surface phenomena exhibit clearly a constant circulation of liquids, and corresponding phenomena, so far as they are observable underground, indicate the persistence of this condition, so that we must infer a subterranean circulation connected with that of the surface. We have then to consider, first, the surface-phenomena, so far as they concern our purpose, and, second, the underground phenomena.

As to the former, we know that it is chiefly the solar energy which initiates the circulation by lifting above the land the water of the sea, and thereby imparting to it the potential energy which is variously exhibited in its return to the sea. The mechanical effects of flowing water† in erosion, transportation, and sedimentation need not occupy us here. As to the chemical effects, we know that the mineral constituents of the rocks, dissolved through this circulation, chiefly find their way in the rivers to the sea. In regions without drainage to the ocean, the dissolved minerals are concentrated by evaporation, which may lead to precipitation. I would remark, however, that in my opinion small proportions of salts are me-

* *Les eaux souterraines a l'époque actuelle*, etc., vols. i. and ii, Paris, 1887; and *Les eaux souterraines aux époques anciennes*, etc., Paris, 1887.

† *Die Wasserfälle des Niagara und ihre geologische Bedeutung*, by F. Pošepný, Vienna, 1879.

chanically taken up in the evaporation of sea-water,* as careful analyses of rain-water have proved, and that this fact leads to the explanation of the salt and salt lakes in regions without drainage, etc.

A. *The Vadose Underground Circulation.*

In connection with the underground phenomena, the *ground-water* has for us a special interest. As is well-known, a portion of the atmospheric precipitate sinks, through open fissures or through the pores of permeable masses, into the rocks, and fills them up to a certain level. When in a given terrain, by wells or other openings, the ground-water (that is, the water-level, *Grundwasserspiegel, nappe d'eau*) has been reached at several points, it is found that these points are in a gently inclined plane, dipping towards the deepest point of the surface of the region, or towards a point where an impermeable rock outcrops. The ground-water is not stagnant, but moves, though with relative slowness, according to the difference in height and the size of the interstitial spaces, down the plane mentioned, and finds its way, in the first instance, directly into the nearest surface-stream, or, in the second instance, forms a spring, which takes indirectly a similar course. Thus stated, free from all complications, the phenomenon exhibits clearly the law of circulation. The atmospheric moisture evidently descends; and even the movement of the upper layer of the ground-water is only apparently lateral, but really downwards, and is determined (for equal sectional areas of the rock-interstices) by the difference in height between the water-level and the surface-outlet.

For that part of the subterranean circulation, bounded by the water-level, and called the vadose or shallow underground circulation, the law of a descending movement holds good in all cases, even in those complicated ones which show ascending currents in parts. The total difference in altitude between the water-level and the surface-outlet is always the controlling factor.

When these two controlling levels are artificially changed, as often happens in mining, the law still operates. In sinking a shaft through permeable ground, it is of course necessary to lift continuously the ground-water. The water-level thus acquires an inclination towards the shaft, which may thus receive not only the flow of the immediate vicinity but even also that of neighboring valley-systems. A

* "Zur Genesis der Salzablagerungen, besonders Jener im Amerikanischen Westen," *Sitz. Ber. der k. Acad. d. W. in Wien*, 1877.

shaft imparts to the previously plane water-level a depression, giving it the form of an inverted conoid with parabolic generatrix. An adit produces a prismatic depression in the water-level; and so on for other excavations. On the other hand, a bore-hole, from which the water is not removed, does not affect the water-level.

Atmospheric waters falling upon impermeable rocks at the surface cannot penetrate them, but must join the existing surface-circulation. The rocks are usually covered with more or less detritus, in the interstices of which the ground-water can move; and the water-level is in most cases at the boundary between the permeable surface-formation and the impermeable rock below.

These relations are complicated by the occurrence of fissures (which the ground-water of course fills), and by the communication of such fissures in depth with permeable formations, which come to the surface somewhere at a lower level, though at great distance. In such cases, as is well known, a siphon-action is set up, and the ground-water of one region may find an outlet far away, even beyond a mountain range.

Peculiar conditions are created by the occurrence of relatively soluble rocks, such as rock-salt, gypsum, limestone and dolomite, in which, by the penetration of meteoric waters and the circulation of the ground-water, connected cavities are formed, constituting complete channels for the vadose circulation.

It is often possible to observe directly, not only the formation but also the filling of these cavities, and thus to obtain valuable material for the explanation of the origin of xenogenites outside the vadose circulation, and not observable in the stages of formation.

It is for our purpose a most valuable fact, that the phenomena of leaching indicate the path of the circulating liquids through soluble rocks, so that we can study the process in its several stages. The water flowing at the bottom of a cave in limestone is unquestionably ground-water; and it follows that the whole complex group of cavities has been eaten out by it. If in another limestone cave we see no flowing water, the current must have found some lower outlet; and the cave represents for us an ancient ground-water channel.

The many and various phenomena of the Karst region are well known: the *Dolins*, *Ponors* and *Katravons*—points where a surface-stream sinks into the earth; vertical openings, at the bottom of which flow subterranean streams; and caves out of which streams issue—illustrating the whole series of the entrance, the course and the exit of subterranean waters.

In 1864, I had opportunity to observe, at Máros Ujvár, in Transylvania, a very instructive illustration of this kind, which is shown in Fig. 1. Here the rock-salt comes to the surface with steep zigzag stratification, and is covered only with detritus, to the depth of a few meters.* Mining is carried on in great parallelopiped-shaped chambers, by means first of levels run horizontally from a shaft, and winzes sunk vertically from these. The workings were at that time 125 meters or 400 feet deep. A great difficulty in the extraction was the entrance of saturated brine from that side of the mine where the Máros river flowed by. Until the mine had been protected by an adit of semi-circular course in the impermeable rock, surrounding the salt-body, the water annually raised and delivered without utilization into the river contained 84,000 tons of salt, or more than twice the weight of the rock-salt mined.

Various investigations have proved that the water of the river passes through the overlying detritus to the salt-body, which it penetrates at the boundary of the impermeable rock of the hanging-wall, finding its way through separate channels to appear as saturated brine, at the deepest point of the mine-workings. These channels had most frequently a cylindrical shape, smooth walls, and sometimes so great a diameter that a man could crawl in. There were always several to be seen, of which, of course, only the lowest in position brought the brine.

The explanation is simple. The water from the river, reaching the salt-body through the detritus cover, acted at the border of the salt, where the principal depressions in the surface were located, and the saturated brine thus formed filled all interstices in the adjoining salt-body. By the leaching of such solutions into each deeper level opened in the mine, a line of maximum activity of circulation was gradually formed, which was followed also by solutions not yet saturated, with additional leaching and the final creation of open channels as the result.

An example on a large scale of such a channel in rock-salt, created, however, without the aid of mining operations, was recently described by H. Winklehner,† who found among other striking phenomena of lixiviation in the rock-salt of the islands of the Persian Gulf, a horizontal natural channel or adit, on the island of Larak,

* "Studien aus dem Salinengebiet Siebenbürgens," by F. Pošepný, *Jahrb. der k. k. geol. Reichsanst.*, 1867, xvii., pp. 506–516.

† "Salzvorkommen in Süd-Persien," *Oesterr. Z. für Berg-und Hüttenwesen*, 1892, xl, p. 581.

which he was able to follow for about 1½ kilom. (1 mile). It expanded in places to caverns 12 m. (39 feet) high, without ever extending outside of the salt.

In precisely the same way were formed the channels in other less soluble rocks, such as limestone, when, the level of the entrance being above that of the exit of the ground-water, a line of maximum activity of circulation was established between the two points. This line, and the cavities developed along it, would not, indeed, always have the regular parabolic course, but would be dependent upon various influences of the stratification, the presence of rocks of unequal solubility, or even an intermixture of impermeable rocks. A mass of the latter, occurring on the line connecting the two points named, might cause the channel to bend up and down, or even in places to assume an upward inclination.

Figs. 2 and 3 illustrate these conditions. S is the soluble, I the impermeable rock; *a*, the entrance-point and *z* the outlet-point of the ground-water; *a b c z*, the line along which approximately a channel might be made, if the impermeable rock were not present. In its presence, the dissolving current must take another road, *a d z*, following more or less the contact between S and I, and in Fig. 2, descending to a depth proportioned to the relation between the original rock-interstices and the hydrostatic head, while in Fig. 3 it first surmounts the dam formed by the impermeable rock, and then plunges towards the outlet *z*. We see that in this way various channels may originate at the contact of permeable and impermeable rocks, as indeed we find them often in nature.

But when to these factors fissures are added, the conditions are essentially changed, for the circulation follows in preference the open fissures, and, if they pass through soluble rocks, enlarges them by solution.

Sometimes the position and the level of the outlet are altered—as, for instance, in the progressive erosion of valleys; and it may then easily happen that the new channel, representing the new conditions, will take a totally different direction, crossing the line of the old one.

Siphon-action is to be observed in soluble, much more frequently than in permeable rocks, as the frequency of intermittent springs in limestone indicates. Such springs presuppose the existence of a siphon-like channel, through which the ground-water cannot flow to escape from the lower leg until the water-level has risen to the top of the bend of the siphon.

We have seen that the ground-water may traverse deep fissures leading to soluble or permeable rocks, and may follow such rocks for considerable distances. When the ground-water, warmed in depth, has an opportunity to reach the surface, such as is given in Fig. 6 by the difference, H, in level, a thermal spring is the result—a so-called *acrotherm*, if its water is not highly charged with minerals, and not unlike the ground-water of the place.

Artesian wells present an analogous case, also explained hitherto by the principle of hydrostatic pressure (see Fig. 7). The outcrop of the permeable layer has been assumed to be necessarily higher than the mouth of the well, in order to account for the rising of the water above the latter level. The cause has been conceived as the operation of communicating pipes, the drill hole being one leg, and the permeable layer the other, and it has been overlooked, that the latter is no open pipe, but a congeries of rock-interstices, in which the water has to overcome a great resistance, and that, perhaps, in level regions no hydrostatic head at all can be demonstrated. Certainly the powerful factor of the higher temperature, and in some cases the gaseous contents, of the ascending water, were omitted from the calculation.

It would be a matter of surprise to me, if the purely hydrostatic and strictly mathematical views heretofore current on this subject had not led to disappointment. I introduce Fig. 7, the conventional diagram of an artesian well, for the purpose of stimulating further thought on the matter.

The Filling of the Open Spaces Formed by the Vadose Circulation.—This is very important genetically, since it is a matter subject to current and direct observation, and capable of furnishing many conclusions applicable to inaccessible subterranean occurrences.

We can observe spaces on the bottom of which, frequently, the ground-water which excavated them is still flowing, and which are therefore filled for the most part with air. Liquids carrying various minerals drip into these spaces and leave a part of their contents on the walls; the cause of deposition being, on the one hand, the evaporation of a part of the liquid, or, on the other hand, such changes as the loss of carbonic acid, precipitating as carbonate the soluble bicarbonate of lime; the oxidation of soluble ferrous to insoluble ferric oxide; the reduction of ferrous sulphate by organic matter to sulphide, etc. The form and structure of these precipitates vary at different parts of the walls. On the roof occur the

stalactites, and on the floor (if it be not covered with water) the corresponding *stalagmites*. The wall-deposits have characteristic forms likewise; so that we can recognize by the appearance of any piece of the deposited mineral the place where it was formed. But from water covering the bottom of the cavity only horizontal deposits can originate. Sometimes the cavity is contracted, so that its whole cross-section is occupied by the liquid. If it is accessible to observation, we can then see that the deposits from the circulating liquid cover the walls uniformly.

This can be much more clearly observed in artificial conduits, where precipitation occurs. We find, for instance, in the pipes which convey concentrated brine, the walls uniformly covered with a deposit, mostly of gypsum. But if air or gas is admitted into the pipes, the deposit occurs only at the bottom. We may thence infer that so long as the circulating liquid fills the whole cavity the attraction of the walls for the precipitated particles is controlling; but that when gas enters, gravity becomes predominant and draws these particles to the bottom.

In opal and chalcedony geodes we can often see both forms of precipitate: the crust uniformly covering the walls, and the horizontal deposit. Fig. 4 represents a geode of iron-opal, from Dreiwasser, in Hungary, in which, besides the crustification and horizontal deposit, stalactitic and stalagmitic forms also appear. A thin crust of translucent hyalite covers all parts of the wall, including the floor. The cylindrical stalactites are also of hyalite. Some of them extend to the bottom, and are perhaps joined to stalagmites rising from the crust there. The remaining space is half filled with a milk-white, opaque, opaline substance, in which occurs a thin layer of translucent hyalite. On the same specimen several other less regular cavities are visible. All of them were lined with the hyalite crust, and some have also the opaline layers. These layers are parallel in all the cavities; and it cannot be doubted that they were horizontally deposited. The stalagmites stand at right angles to them, and were unquestionably vertical when formed. The geode certainly occupied, therefore, at the place of formation, the position shown in Fig. 4.

I must resist the temptation to describe the manifold forms of deposit in limestone caves. Fig. 5, an ideal diagram, showing a wall-accretion, and stalactites and stalagmites, separate and grown together, is given, not to illustrate the variety of the phenomena, but to indicate their analogy with those of the little geode in the iron-

opal of Fig. 4. It is easy to conceive, that, under some circumstances, particularly in old cavities, lying above the water-level and not subject to further enlargement, the formation of stalactites, etc., might ultimately fill the whole space.

The floor of caves often shows deposits colored with ferric oxide, the explanation of which is obvious. Sometimes we find in the upper caves traces of sediments also; and, in one instance I found in an outlet-cave pebbles of very hard rocks, which certainly came from the surface.* The chemical reaction of the formation and filling of these caves are so simple as to need no discussion here.

Much more various observations, however, can be made in the *artificial caves*, formed by mine-workings. Here we have conditions analogous to those of the natural caves, but much greater variety, since the most widely different substances come into play. The mine-workings are situated at an artificially depressed water-level, and will show, in general, processes analogous to those observed in limestone caves, particularly the formation of stalactites. From calcareous rocks, from mineral deposits, and from the mine-masonry, crusts, stalactites and sinter are formed, analogous to those which occur in cavities at the natural water-level. Processes of oxidation will here also play the leading part, although reduction may also be effected through the more abundant organic matter in the mine-waters. Thus stalactites of pyrites, evidently reduced from ferrous sulphate by organic matter, are often found in metal-mines. A respectably large number of observations already illustrates the processes which are going on under our eyes in mines, and from which we can draw conclusions as to the destruction and creation of many minerals by circulating under-ground solutions. But we must not forget that these proofs apply only to the conditions of the shallow or vadose circulation, and that, for the explanation of the formation of the more ancient deposits, we must look to the rock-regions below the water-level.

In order to give at least one American example, I refer to the observation of Raymond, who found in an old Spanish mine, in the Cerillos range of New Mexico, an iron pick-axe, the eye of which was filled with beautifully crystallized galena, evidently a reduction of lead sulphate by the decaying wood of the handle of the pick.†

It may be said, in general, that the results of the processes of

* "Geol. mont. Studie der Erzlagerstätten von Rézbánya in S. O. Ungarn," von F. Pošepný, *Ung. geol. Gesellsch.*, 1874, p. 48.

† *Trans. A. I. M. E.*, 1883, xi., p. 120.

oxidation, chlorination, and reduction, observed in those regions of ore-deposit which lie above water-level, have come to pass under conditions analogous to those just described; so that we are able to adduce extended series of proofs, not only as to formations now going on, but also as to similar formations long since finished.

B. *The Deep Underground Circulation.*

Thus far, we have considered only such processes as take place in the region above water-level, and are still, in some cases, open to our observation. As we descend to a deeper region, there is less hope of encountering formative processes still active. When we penetrate by mining into the depths, we artificially depress the water-level, and create conditions unlike those which attended the formation of the deposits.

But, if we compare the deposits formed below water-level, under proportionally greater pressure and at higher temperature, with those of the upper region, it appears beyond doubt that the former also must have been produced by deposition from fluid solutions.

When we compare the low solubility of certain ingredients of the deposits with the spaces in which they occur, often in large quantity, it is impossible to assume that they could have been precipitated from solutions existing in these spaces only. We must concede that immense volumes of solutions must have flowed through the spaces —in other words, that the deposits were precipitated from liquids circulating in these channels.

The formation of these cavities has been already discussed, and referred to mechanical and chemical causes. It remains to consider the manner of their filling. We have seen that the uppermost layer of the ground-water has an apparently lateral, but really descending movement; and it is very natural to imagine that this top layer slides, as it were, upon a lower mass, which is apparently stagnant. According to this conception, the deep region would be comparable to a vessel filled with various permeable, impermeable, and soluble materials, over which water is continually passed, so that, from the moment when all the interstices have been once filled, only the uppermost water-layer has any movement.

But, with increase of depth, the pressure of the water-column increases, as does the temperature. The warm water certainly tends to rise, if not prevented by interstitial friction, as is, no doubt, generally the case. But where the warmed water finds a half-opened channel communicating with the upper region, it will experience

much less friction on the walls, and must evidently ascend. It might thus be conceived that the ground-water descends by capillarity through the rock-interstices over large areas, in order to mount again through open channels at a few points.

This subject was viewed by A. Daubrée in a much wider significance, and extended to cover the origin of volcanic phenomena.* He propounded the inquiry, whether the enormous quantities of steam which are daily liberated from the deeper region are continually replaced from the surface, and if so, how? He pointed out that this water-supply could not take place through open fissures, in which the liquid water descended at one time and the steam ascended at another, but he showed that the descent could be effected through the porosity and capillarity of the rocks. Jamin's experiments have taught us the influence of capillarity upon the conditions of the equilibrium established by means of a porous body introduced between two opposing columns. Daubrée constructed an apparatus in which the temperature in one part of the capillary passage was so high that the liquid must assume the form of steam, and thus escape the operation of the laws governing its infiltration. This apparatus comprised a sandstone slab, with water above and a chamber below, the latter provided with a manometer for measuring the pressure of the steam collected in it. The whole was exposed to a temperature of about 160° C. (320° F.), and steam collected in the chamber of 68 cm. mercury-column, indicating about 13 pounds over the atmospheric pressure in the manometer, or a total pressure of about 1.9 atmospheres. This steam could only come from the water above the sandstone through which, in spite of the pressure, a capillary filtration took place.

"The difference in pressure on the two sides of the stone not only did not drive the liquid back, but permitted it to filter quickly from the colder side (100° C. = 212° F.) to the hotter (160° C. = 320° F.), and favored the rapid evaporation and the drying of the hot stone surface" (*op. cit.*, p. 184).

"According to these experiments, therefore, water may be forced by capillarity, operating in the same direction as gravity, against a strong interior counter-pressure, to descend from the shallower and cooler regions to deeper and hotter ones, where, by reason of acquired temperature and tension, it is capable of producing great mechanical and chemical effects" (*op. cit.*, p. 186).

Daubrée's experiment confirms our view that the portion of the ground-water lying below water-level is not stagnant, but descends by capillarity, and since it cannot be simply consumed in depth, re-

* *Synthetische Studien zur Experimentalgeologie*, by A. Daubrée; German translation by Dr. A. Gurlt, Brunswick, 1880, p. 180.

ceives there through a higher temperature a tendency to return towards the surface, which tendency is most easily satisfied through open channels. Stated summarily:* The ground-water descends in the deep regions also through the capillaries of the rocks; at a certain depth it probably moves laterally towards open conduits, and, reaching these, it ascends through them to the surface.

The solvent power of the water increases with temperature and pressure, and also with the duration of its underground journeying. Hence, while it is descending, it can dissolve or precipitate only the more soluble substances. But the ascending current in the open conduits is undoubtedly loaded more heavily and with less soluble substances, which, as the conditions of their solubility (temperature and pressure) gradually disappear in the ascent, must be deposited in the channels themselves.

The open channels, in which the solutions ascend, are not the deductions of theoretical speculation. They really exist, as we can prove by induction from appropriate observations.

The Ascending Waters Encountered in Mines.—A number of such phenomena are adduced by H. Müller.† For instance, in the Gottes Geschick mine, near Schwarzenberg, in the Erzgebirge, at the depth of 110 m. (360 feet) an acid spring containing CO_2 and H_2S emerges from a nickel- and cobaltiferous-silver ore-vein (*op. cit.*, p. 286). At the Wolkenstein Bad, an acid spring comes from the druses of an ore-vein containing a crust of barytes and amethyst. In the Alte Hoffnung Erbstollen mine, near Mitweida, bad air and exhalations of carbonic acid led, in 1835, to an analysis of the ground-water, which proved to be weakly acid. In the Churprinz mine at Freiberg a warm (25° C. = 77° F.) acid spring was struck on the Ludwig Spat vein at the depth of about 160 m. (525 feet). Besides these, Müller names a number of mineral springs occurring in Bohemia and Saxony at the outcrops of mineral veins never opened by mining. In spite of the great reserve which he exhibits, he summarizes his view as follows (*op. cit.*, p. 307):

"Mineral veins and mineral springs are certainly adapted to complement each other in genetic theory. On the one hand, the ore-veins, as extended, indefinitely deep fissures, gradually filled, indicate a very profound origin for the mineral

* *Ueber die Bewegungsrichtung der unterirdisch circulirenden Flüssigkeiten*, von F. Posepný. *Extrait du compte rendu de la 3me. session du Congrès géologique international.* Berlin, 1885, p. 71.

† "Ueber die Beziehungen zwischen Mineralquellen und Erzgängen." Cotta's *Gangstudien*, vol. iii., 1860, p. 261.

springs, and suggest variations caused by time and circumstances in the amount and mutual reactions of their contents, solid or volatile; and, on the other hand, the present relations of mineral springs explain the mode of ingress and deposit of the constituents filling the veins."

Soon after this publication (I think in 1864), a thermal spring of 23° C. (73° F.) was struck at the depth of 533 m. (1774 feet) in the Einigkeit shaft, at Joachimsthal, and in the same mine at two other points similar mineral springs, rising with strong pressure, were exposed. They prevented further increase in depth of that part of the mine, and were plugged as far as practicable. The analyses made in 1882 showed that they were acid springs containing considerable silica (33 grammes per ton). In one of them arsenic was also proved to the extent of 22 grammes per ton.*

The mineral waters of the Joachimsthal mines are said to come in contact, near the place where they were encountered, with basalt-like rocks (called *Wacken*), which traverse the ore-veins, and are, therefore, of later origin. In general, most of the ore-deposits of the Erzgebirge appear to have a decidedly recent origin, but even from this standpoint the mineral springs found in mining are to be regarded as nothing else than the continuation of those ascending liquids which have filled the ore-veins. Mining depresses the water-level, so that mineral waters circulating in the neighborhood are forced to those points in the mine where there is only atmospheric pressure.

This "neighborhood" may, indeed, extend to a comparatively long distance. For instance, the thermal spring at Carlsbad, which is the nearest to Joachimsthal, is 17 kilom. (10.5 miles) away and 380 m. (1246 feet) above sea-level, while the spring in the Einigkeit shaft at Joachimsthal was struck at 206 m. (675 feet above sea-level, that is, 174 m. (571 feet) lower than Carlsbad. The irruption of the thermal waters of Teplitz in Bohemia into the lignite-mine of Dux, 7 kilom. (4 miles) away, which took place first in 1879, and has occurred recently since, shows plainly that subterranean communications may thus be established for long distances by mining.†

* Since the metric ton of 1000 kilo., or the weight of m.^{3} (1 cubic meter) of water, is a rational unit of weight, I refer all tenors to it, and state them in grammes or milligrammes to avoid decimals. Thus 22 grammes per ton represents 0.022 per thousand, or 0.0022 per cent.

† "Einige, die Wassereinbrüche in die Duxer Kohlenbergbaue betreffende, geologische Betrachtungen," von F. Pošepný. *Oesterr. Zeitsch. f. Berg-u. Hüttenw.*, 1888, xxxvi., pp. 39–54.

Additional data for the study of these relations are furnished by the miners on the Comstock lode, where, with the advancing depth of operations, ascending thermal waters were unexpectedly encountered, the abundance and high temperature of which presented extraordinary obstacles to mining. The great richness of the deposit was the reason that the hope of going deeper was not abandoned, as in Joachimsthal, where the only effort was to dam out the waters from existing workings; but that, on the contrary, the struggle was accepted against the waters themselves and the enormous heat which they caused in the mines.

As is well known, the upper workings on the Comstock, before any ascending waters had been encountered, were not specially hot, though warmer (21° to 24° C, or 70° to 75° F.) than other mine-workings in similar positions. Dr. F. Baron v. Richthofen noticed no abnormal mine-temperature, although he ascribed the Comstock to earlier solfataric action.*

At a later period, upon the cutting through of clay-partings in the rock, the hot water repeatedly broke into the workings with great force, as, for instance, in the North Ophir mine, when, according to Clarence King, † the workmen had scarcely time to escape. The water is said to have had a temperature of 40° C. (104° F.), and filled the workings immediately to a height of 30 m. (100 feet). In another case the water broke into the 2200-foot level of the Savage mine, and filled the large spaces both of that mine and of the Hale and Norcross up to the 1750-foot level, or to a height of 137 m. (450 feet). Gas was continually but not violently evolved and although Prof. J. A. Church ‡ reports it to have been under a pressure of 200 pounds per square inch, he believes that this was not a gaseous, but a hydrostatic pressure.

The water which in 1880 flooded the Gold Hill mines came from a bore-hole in the Yellow Jacket shaft, at a depth of 939 m. (3080 feet); had, according to George F. Becker,§ a temperature of 77° C. (170° F.); and was heavily charged with hydrogen sulphide. In the upper levels of the mine, Becker says there is evidence of the presence of carbonic acid, and on the 2700-foot level where the tem-

* *The Comstock Lode, Its Character and Probable Mode of Continuance in Depth*, San Francisco, 1866, p. 54.

† *U. S. Geol. Expl. of the 40th Parallel*, vol. iii., *Mining Industry*, Washington, 1870, p. 87.

‡ *The Comstock Lode, Its Formation and History*, New York, 1879, p. 207.

§ "Geology of the Comstock Lode," etc., *U. S Geol Survey, Monograph* iii., Washington, 1882, pp. 230, 386.

perature was 66° C. (150° F.) a deposit of sinter was found, consisting mainly of carbonates. Church (p. 206) remarks, that it was at first believed that the repeated irruptions of water came from chains of cavities existing in the rock, but that at the time of his visit the conviction was that they came through shattered and decomposed seams, parallel with the lode, and sometimes of great thickness.

Systematic and long-continued temperature-observations in several Comstock mines enabled Becker to represent comprehensively for different lines the increase of temperature with depth; and it thus appeared that this increase was greatest in the vicinity of the lode, diminishing with the distance from the lode; that the vehicle of heat was the water; and hence that it was through the lode itself that communication with the hot depths took place, and the phenomenon denominated "solfataric action" by Richthofen was caused.

The chemical constitution of these intruding waters will be considered further on, after certain phenomena occurring nearer to the surface have received attention.

Related Phenomena Near the Surface.—A sort of transition to the corresponding phenomena on the surface itself is illustrated by the mines at Sulphur Bank, Cal., which have furnished some of the most important data contributed by America to the study of the genesis of ore-deposits.

This is a once rich, but now (apparently) practically exhausted quicksilver-mine, in the working of which not only thermal waters but gaseous emanations were encountered as obstacles. At the time of my visit in 1876, an open-cut exploitation was in progress, the terraces of which had extended in some places about 5 m. (16 feet) below the natural surface. Sulphur, as well as quicksilver, was won; but it subsequently appeared that the sulphur-deposit was confined to the uppermost zone, while the quicksilver (or cinnabar) extended in considerable proportions to deeper regions.

At that time I found sulphur and cinnabar in a decomposed basalt, partly as the filling of irregular fissures, traversing the rock in all directions, partly as impregnations in the rock itself, which had often been reduced to a porous mass. The process of decomposition proceeded unquestionably from the fissures, which, moreover, gave forth hot mineral waters and gases. The odor alone was sufficient proof that the gases contained H_2S, to the oxidation of which into H_2SO_4 the acid reaction of the rock and its moisture was to be ascribed. The miners (mostly Chinese) chiefly followed in

extraction the fissures (partly because it was the easiest way to make rapid progress; partly because the richest ores were there concentrated); and, as a result, large round blocks, often several meters in diameter, were left standing. These had a distinct shaly structure, but were so loosely held together that a kick would reduce them to ruins. In the interior of the larger, light-gray blocks, was often found a nucleus of solid, dark, undecomposed rock. (Some of these *nuclei* I have added to the collection of the Przibram Mining Academy.)

The cracks were filled chiefly with an opaline mass, in which a white, opaque ingredient was variously kneaded, as it were, with a gray to black one, translucent at the edges. The specimens taken fell into irregular pieces, bounded by fissures, evidently the result of loss of volume or loss of moisture by the opaline mass.

The cinnabar formed either distinct mineral crusts in the crevices or impregnations of the porous neighboring rock. This was true of the sulphur also; only, the latter appeared, as a rule, in crystalline aggregates upon the cinnabar crusts—an indication of its later origin. Occasionally the cinnabar was deposited in beautiful crystals on the fissure-walls, but these were generally so loosely attached that it was difficult to secure a specimen.

The pyrites, mostly disseminated in the rock, tended so strongly to decomposition, evidently by reason of its saturation with sulphuric acid, that specimens containing it soon fell to pieces.

These observations suffice to show that in this case hot mineral waters ascend through fissures containing ore-crusts and opaline deposits; and when it is considered that the deposit of amorphous, hydrated silica is unquestionably the work of the mineral water which decomposed the rock, and also, that the cinnabar occurs in the interior of the opaline mass, the two phenomena cannot well be separated, and it must be assumed that a metallic sulphide has here been deposited from an ascending spring. Fig. 10 represents the exposure as sketched in my note-book.

Later developments exhibit these relations still more clearly. Le Conte and Becker* found a shaft 50 m. (164 feet) from the basalt,

* "The Phenomena of Metalliferous Vein-Formation, Now in Progress at Sulphur Bank," by J. Le Conte and W. B. Rising, *Am. Jour. of Sci.*, 1882, cxxiv., p. 23.
"On Mineral Vein-Formation, Now in Progress at Steamboat Springs, Compared with the same at Sulphur Bank," by J. Le Conte, *Am Jour. of Sci.*, 1883, cxxv., p. 424.
"Geology of the Quicksilver-Deposits of the Pacific Slope," by G. F. Becker, *Monograph* xiii., *U S. Geol. Surv.*, Washington, 1888, p. 251.

about 92 m. (310 feet) deep in sandstone, from which drifts had been run northward at different levels under the outcrops of the deposit. It is to be regretted that their reports are not accompanied with precise descriptions of the mine-workings. In the third level (64 m. = 210 feet below the surface) the drift was 70 m. (232 feet) long, "cutting through the ore-body and reaching only barren rock on the other side. The fourth level has been pushed 41 m. (136 feet), and has reached the ore-body." From these data it is hardly possible to form an idea of the position of the ore-body traversed.

The data given concerning the interior structure of the deposits are, however, important. Sandstones and slates are here broken up by fissures in such a way as often to form a breccia. Whether the fragments belong together, and whether they present the relation which I have denominated typhonic, is not stated; but it may be inferred from the sketch of an ore-specimen from this place that the fragments do not belong together, and that their condition has been brought about by more extreme dislocations. The subject is highly important for us; and I have attempted in Fig. 11, although the original is not before me, to represent it according to Le Conte's sketch, so as to place it side by side with other phenomena, thoroughly familiar to me.

The fragments of slate and sandstone have somewhat rounded edges, and leave varied interspaces, which are filled, partly with a still soft or already indurated paste, containing finely disseminated metallic sulphides, partly with cinnabar, for the most part in coherent crusts. A part of the space is usually empty, exhibiting what I call a central druse. Sometimes, it is said, the rock-fragments are cemented together with massive cinnabar, and kernels of rock crusted with cinnabar occur frequently.

Hot mineral water and gases carrying H_2S force their way through the interstices of the deposit, as was the case observed in the upper zones. The silica deposits are found in all stages of consolidation, from a gelatinous mass to chalcedony, and (Le Conte, *op. cit.*, p. 29) alternate with layers (crusts) of metallic sulphides (cinnabar and pyrites). Becker examined the whole neighborhood, and extended his studies to similar ore-deposits of the region. He does not consider the basalt of Sulphur Bank, as do G. Rolland* and Le Conte, to be a lava-stream, but takes it to be an eruptive rock, originating on the spot, which has overflowed a fresh-water formation of recent

* "Les Gisements de Mercure de Californie," *Annales des Mines*, 1878, vii., Série t. xiv., p. 384.

age. The bottom proper is a Cretaceous sandstone. The ore-bearing character extends from the basalt (about 16m. = 52 feet thick) through the fresh-water layers into the Cretaceous sandstone. Concerning its relations in the middle layer we have no data, which is unfortunate, since the effects of the acid waters upon this calcareous material must have been considerable, and it is not unlikely that the deposit had in this region a totally different character. Fresh-water formations adjoining the deposit have preserved to a remarkable degree plant-roots etc., transformed into lime carbonate; and it would be very instructive to study their forms as metamorphosed by the mineral water.

Concerning the chemical constitution of the warm (80° C. = 176° F.) water, I shall speak further. According to Becker's analysis (*op. cit.*, p. 259), it is extraordinarily rich in chlorides, borax and sodium carbonate. The gas liberated from it often proved to be ammoniacal, and consisted in 1000 parts of 893.4 parts CO_2, 2.3 parts H_2S, 79.4 parts CH_4 (marsh-gas) and 24.9 parts nitrogen.

As to the presence of other metals besides mercury, it is worthy of mention that Dr. Melville found small amounts of gold and copper in the marcasite accompanying the cinnabar, and that G. Becker found in the efflorescence from the mine-workings, besides the substances detected in the mineral water, traces of cobalt and nickel.

As will be seen, this deposit furnishes genetic data, concerning not only the ores of quicksilver, but also those of other metals. An ascending mineral spring here passes from the deep into the shallow region, and suffers, besides the reduction of pressure and temperature, the oxidation of its H_2S, from which result a strong acid and the deposition of sulphur nearest the surface.

In depth no sulphur is found, but sulphides of quicksilver and iron, upon or within deposits of silica, both being in distinct alternating mineral crusts. It cannot be doubted that cinnabar and pyrites, on the one hand, and silica, on the other, have been precipitated from the solution which still ascends in these channels. At most, it may be doubted whether this precipitation is still going on. Le Conte adduces in support of the probable continuance of the process the occurrence of silica sometimes gelatinous and soft, as if recently precipitated. Becker and Melville tried to obtain direct evidence of the presence of quicksilver dissolved in the ascending mineral water of to-day, but their careful investigations failed to find it. Although the water contains ingredients in which quick-

silver is soluble, there is no quicksilver dissolved, and it must have been already precipitated by some agent—as they suggest, ammonia.

There are among geologists unbelieving Thomases enough, who will believe in the presence of quicksilver in the mineral solution only when it has been actually precipitated for them; but there are those, on the other hand, who are convinced by the evidence thus far gathered that the sulphide deposits of this locality proceeded from the ascending thermal spring, whether the process of precipitation is still going on or not.

Equally weighty data are furnished by Steamboat Springs in Nevada, to which Laur and J. A. Phillips first called attention, and which Le Conte and Becker investigated thoroughly.* In a valley surrounded with eruptive rocks, but underlain chiefly by Archæan rocks, thermal springs may be seen at several points emerging from north-and-south fissures. The action of these springs has covered the ground with a sinter-deposit, predominately of lime carbonates, about 15 m. (49 feet) thick. In this sinter may be traced many fissures, here and there still open, but mostly closed by the deposit of silica on their walls. According to a sketch given by Le Conte, these very clearly crustified deposits extend somewhat above the general level of the surface, forming single mounds or chains of mounds.

From some of them hot vapors and gases still issue, chiefly CO_2 containing H_2S. In others, such emanations have been so greatly diminished that only by listening can the liberation of vapor in depth be perceived. Some of the fissures are completely filled, and give forth neither mineral water, steam nor gas.

In the group, about 200 m. (656 feet) wide and 1 kilom. (0.6 mile) long, which lies nearest to the railway-track, these phenomena are most strikingly exhibited. Besides the principal substances mentioned below in the table, Becker found in this mineral water also small amounts of metallic compounds, as, for instance, HgS, a trace of Na_2S, 1.0 gramme per ton of Na_2SbS_3, and 8.7 grammes per ton of Na_2AsS_3.

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* M. Laur, "Sur le gisement et l'exploitation de l'or en Californie," *Annales des Mines*, 1863, vi. Série, t. iii., p. 423.

J. A. Phillips, *Phil. Mag.*, 1871, xlii., p. 401. Also, *A Treatise on Ore-Deposits*, London, 1884, p. 70.

J. Le Conte, "On Mineral Vein-Formation, Now in Progress at Steamboat Springs Compared with the Same at Sulphur Bank," *Am. Jour. Sci.*, 1883, cxxv., p. 424.

G. F. Becker, "Geology of the Quicksilver-Deposits of the Pacific Slope," *Monograph* xiii., *U. S. Geol. Survey*, Washington, 1888, p. 331.

About 1½ kilom. (1 mile) to the west is a group of similar fissures, yielding some steam and CO_2, but no mineral water. In the mineral crusts of these, however, several metallic sulphides occur. In 1863, Laur declared that he had seen in them distinct traces of gold. In 1878, one of these fissures was opened by an adit, about 15 m. (49 feet) under the surface, and produced a vein-matter carrying cinnabar, which was mined for a while as quicksilver-ore. The temperature of this mine was not so high as to cause serious trouble to the workmen

G. F. Becker carefully analyzed the filling of several fissures, and found, besides hydrated ferric oxide, considerable quantities of Sb, As, Pb, Cu, and Hg sulphides and gold and silver, as well as traces of Zn, Mn, Co and Ni. Since from 1 to 3.5 kilog. (2.2 to 7.7 lbs.) of the vein-stuff were employed for each analysis, the results are specially trustworthy, and I give the records of three analyses here, expressing them in grammes per ton (1 ton = 1,000,000 grammes):

	I.	II.	III.
Sulphides of antimony and arsenic,	.....	23,000.0	150.0
Ferric oxide,	.....	2,500.0	.....
Sulphide of mercury,	1.4	2.5	1.0
Lead,	88.0	21.0	.....
Copper,	0 3	12.0	.....
Gold,	0.9	1.0	.....
Silver,	0.3	0.3	.....

(Considering the gold and silver to be alloyed in the above proportions, we should have bullion 0.750 and 0.769 fine, which is the general grade of the so-called "free gold" of Transylvania.)

The careful study of the phenomena, particularly by G. F. Becker, leaves no doubt that in this case ascending mineral waters have deposited, besides the various forms of silica (from opal to crystalline quartz), different metallic sulphides, and that the fissure-fillings exhibit a very clear instance of crustification. It is, indeed, not proved that the process is now going on. But that is not the main point. We may be content to have the proof that it has taken place.

Mineral Springs at the Surface.—When we isolate a spring characterized by high temperature, a large quantity of gas or of matter in solution, we notice at once that its level is higher than that of the ground-water. The more thorough the isolation or walling-in, the more striking is this phenomenon, so clearly unlike that of the vadose or shallow circulation.

Isolation is usually performed by digging as deep as possible, so

as to get at the spring below the loose surface-material in an impermeable rock, and then by building a well-pit, to give it freer ascent. But since the circulation of the ground-water in the loose surface is very lively, the necessary depression of the water-level in such an excavation involves the lifting of large quantities of water. Moreover, the escape of gas from the mineral spring often hinders the operation; so that there is, as a rule, little opportunity for thorough investigations. Cases in which accurate observations have been properly recorded for preservation are very rare.

The first good fissure encountered in the bed-rock is deemed to be the channel of the mineral spring, and the well is built over it. Complete isolation from the ground-water is probably seldom practicable. Nevertheless, the mineral spring, being under higher pressure than the ground-water, will tend to exclude it from the well. The imperfection of the isolation is shown, however, when we try for any reason to pump out the well. To lower the water-level, say 1 m. (3.28 feet), we have to raise many times the amount of water which the spring itself would normally furnish (even taking into account the decreased pressure, which affects the flow in the proportion of the square root of the head). The excess, generally surprisingly great, comes from the ground-water which finds its way into the well.

If we allow the mineral water to ascend again quietly in the well, the level rises at first rapidly, then slowly, and finally remains (in the absence of change in the height of the ground-water and in the barometric pressure) stationary at a certain height above the ground-water level. This difference of height represents the ascensional force of the mineral spring.

If the spring makes a deposit at its mouth (mostly of lime carbonate, hydrated ferric oxide, and silica) it may thus build a conduit, extending above the ground-water level and the surface to the height represented by its ascensional force. Thus, we find conical mounds from the top of which mineral springs flow. This phenomenon is shown in the highest degree by geysers, *i.e.*, thermal springs in which paroxysmal developments of steam and gas occur, often forcing the water to notable heights. Some of the magnificent geysers of the Yellowstone National Park have built chimney-like conduits of considerable size. Their structure has much similarity to that of stalactites; indeed, we may recognize generally, in the various deposits of ascending mineral springs (in other words, in the products of the deep circulation), many analogies with the vadose circu-

lation. This circumstance indicates a relation between the phenomena of the two regions which is often entirely ignored or even denied.

While, for instance, the geysers have a temperature above boiling-point, some mineral springs rise but little above the mean local temperature of the surface or of the ground-water. This may be especially observed in the acid springs; yet, these are also ascending springs, and must have been formed in the deep region.

Within the vadose region we have, sometimes, ascending waters, which are, however, mostly to be explained by hydrostatic pressure. But, within the deep region, hydrostatic pressure can play no part; and here it is the higher temperature and the presence of gas which cause the ascension of mineral springs. The extreme instances of this kind, such as geysers, steaming springs, mud-volcanoes, petroleum springs, etc., nobody will undertake to explain by hydrostatic pressure, and more moderate results of the same factors can scarcely, with consistency, be so explained.

It is a striking circumstance that ascending springs occur chiefly in the neighborhood of the later eruptive rocks, such as trachyte, basalt, etc. This is emphatically the case throughout the zone which crosses Europe from west to east, in France, Germany, Bohemia, Hungary, and Transylvania. Here the warm springs and the acid springs occur thickly, while north and south of this zone they are only sporadic. Their connection in the zone with the eruptive rocks is evident, and they are often considered as the last echoes of the processes of eruption. The sporadic springs, in places where eruptive rocks play no part, must have come through deep fissures of dislocation. For example, the line of the fault along which the Alps sank below the Tertiary basin of Vienna is marked by a complete series of thermal springs.

This circumstance has another and far-reaching significance. For ore-deposits are similarly distributed. They are most numerous and most closely grouped in the neighborhood of eruptive rocks, especially extended zones of eruptive rocks, as in the American West, and in Hungary and Transylvania, while among other rocks they are fewer and more scattered.

Chemical Constitution of Mineral Waters.—Ascending mineral springs have widely varying composition; some, like the "aerotherms," representing strictly only warmed ground-water, while others are strongly mineralized, and carry some substances almost to saturation. The material bearing on this subject is too voluminous

and heterogeneous to be fully cited and discussed here. I must be content with the exhibit of a few analyses, specially interesting for the present purpose.

The following is a list of the localities, etc., represented in the table on page 234:

Waters Encountered in Mines.

No.	Locality.	Temperature. °C.	Temperature. °F.	Authority.
1	Gottes Geschick mine, Schwarzenberg,	11.	51.8	R. Richter.
2	Einigkeit shaft, Joachimsthal,	28.7	83.7	J. Seifert.
3	The "Sprudel," in Colliery at Brüx, Bohemia,			J. Gintl.
4	Comstock, Savage, 600 foot level,	28.3?	83. ?	S. W. Johnson.
5	Comstock, Gould and Curry, 1700-foot level.			
6	Comstock, Gould and Curry, 1800-foot level.			
7	Comstock, Hale and Norcross,	67.8?	154. ?	
8	Comstock, Ophir,	21.1?	70. ?	George Attwood.

Water in Ore-bearing Fissures.

No.	Locality.	Temperature. °C.	Temperature. °F.	Authority.
9	Sulphur Bank, Hermann shaft,	70. ?	158. ?	G. F. Becker.
10	Sulphur Bank, Parrott shaft,	70.	158.	G. F. Becker.
11	Steamboat Springs,	75.	168.	G. F. Becker.

Some Bohemian Thermal Springs.

No.	Locality.	Temperature. °C.	Temperature. °F.
12	Sprudel, Carlsbad,	64.	147.2
13	Kreuzbrunn, Marienbad,	12.	53.6
14	Wiesenquelle, Franzensbad,	13.	55.4
15	Urquelle, Teplitz,	50.	122.

Weak and Strong Mineral Springs.

No.	Locality.	Authority.
16	Ottoquelle, Giesshübl,	Dr. Novak Kratschmann.
17	Josephsquelle, Bilin (1875),	Dr. Ruppert.
18	Puits de l' Enclos des Celestins, Vichy,	Bunsen.
19	Rippoldsau, Josefquelle (1875),	Bunsen.
20	Rippoldsau, Wenzelquelle (1875),	Bunsen.
21	Rippoldsau, Leopoldquelle (1875),	Bunsen.
22	Kissingen, Pandurquelle (1856),	Liebig.
23	Kissingen, Rákoczyquelle (1856),	Liebig.
24	Yellowstone, Cleopatra, Mammoth Hot Springs (1888),	F. H. Gooch.
25	Yellowstone, Grand Geyser,	T. E. Whitefield.

It is well known that analysts in combining their results do not follow the same rule. One supposes a certain acid to be united with

Analyses of Some Ascending Waters.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
One Thousand Kilogrammes of Mineral Water contain, in Grammes:																									
Alkal. carb...	1150	352	2297	145	110	449	460	70	1954	325	333	2356	167	1167	415	1312	3374	5437	.....	.....	.....	.....	.....	.....	378
Earthy "	510	55	729	51	.....	.....	.....	48	54	57	17	127	146	381	100	565	586	981	1257	1170	1653	1110	1087	625	9
Alkal. sulph..	82	12	37	.....	.....	.....	.....	57	.....	689	172	2535	500	3339	23	34	954	314	1273	1105	917	.....	.....	145	39
Earthy "	.....	.....	6	535	246	286	386	222	23	.....	.....	.....	.....	.....	56	.....	.....	.....	299	240	37	978	892	559	0
Chlorides.....	62	6	58	2	1	20	23	10	1150	1115	1612	1031	170	1213	63	30	381	534	85	69	44	6441	5998	304	619
Silica.....	.....	51	72	31	38	69	60	38	37	42	391*	73	8	61	48	59	43	65	57	97	86	13	4	52	303
Other subst....	.....	.....	6	.....	.....	.....	.....	5	1883†	2412†	325†	.....	120	34	13	5	1	84	5	17	20	15	9	46	42
Total.....	1804	476	3205	764	395	824	929	450	5101	4640	2850	6126	1111	6195	718	2005	5339	7415	2976	2698	2757	8557	7990	1731	1390
One Thousand Grammes of Solid Residuum contain, in Grammes:																									
Alkal. carb...	632	739	717	118	278	545	495	156	383	70	117	384	150	188	577	655	631	735	.....	.....	.....	.....	.....	.....	273
Earthy "	288	115	227	67	.....	.....	.....	107	10	12	6	28	135	61	139	283	108	132	422	436	601	130	136	362	6
Alkal. sulph..	46	24	11	.....	.....	.....	.....	125	.....	148	60	409	450	539	32	17	183	42	427	412	332	.....	.....	84	28
Earthy "	.....	.....	2	699	623	347	415	492	5	.....	.....	.....	.....	.....	77	.....	.....	.....	100	88	13	114	111	323	.....
Chlorides.....	34	12	17	2	2	24	25	23	225	242	569	166	153	195	87	15	70	72	28	22	16	754	751	175	445
Silica.....	.....	107	22	40	96	83	64	83	7	9	137	12	8	10	61	30	8	8	18	36	31	1	1	30	218
Other subst...	.....	23	14	74	1	1	1	14	370†	519†	111†	1	104	7	27	.....	.....	11	5	6	7	1	1	26	30
Total.....	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

* Sodium quadrisilicate, $Na_2 Si_4 O_9$. † Mostly sodium biborate, $Na_2 B_4 O_7$.

an alkali; another gives the same acid to an earthy base, etc. What interests us in the comparison afforded by the table is the substances occurring in large proportions, the carbonates and sulphates of the alkalies and alkaline earths; the chlorides, the silica, and the quantity of organic matter (if it were determined by a uniform procedure).

I deem it most convenient to take 1 ton of 1000 kilogrammes (representing, for waters not too rich in mineral, the weight of 1 cubic meter), and to express the weights of the salts in grammes, to avoid decimals. In order to show the relations of the salts, one to another, it is well also to represent them on the basis of 1000 parts of the solid matter.

For the Comstock waters, the rationally-stated analysis of S. W. Johnson, from the 600-foot level of the Savage mine (C. King, *op. cit.*, p. 87), served me as a guide, according to which I have recalculated the figures (Church, *op. cit.*, p. 204), for other mines and levels.

These analyses show the irruptive waters on the Comstock to be poor in dissolved substances. According to the determination of solid residuum by E. S. Bristol (C. King, *op. c.*, p. 88), this would not be the case. He finds the mine-water of the 500-foot level to contain in the Savage north drift 2660 grammes, and in the Yellow Jacket west drift as much as 3271 grammes of solid material in one ton (1000 kilos.). But it is a question whether these figures do not refer to ordinary mine-waters, as the term west drift seems to indicate.

The predominance of sulphates over carbonates is nothing unusual; but the decided predominance of lime sulphate, or gypsum, in the Comstock waters is unique. This relation would still remain if we should reckon a part of the sulphuric acid as combined with the alkalies. The two most trustworthy analyses of Attwood and Johnson give 222 and 535 grammes of gypsum per ton of water, and 492 and 699 grammes per 1000 grammes of dry residuum. Apart from their gypsum, the Comstock irruptive waters may be classed among the weak or acrothermal springs, like those of Teplitz in Bohemia.

The Sulphur Bank and Steamboat Springs waters are distinguished from all others in the table by a considerable proportion of sodium biborate, and resemble unmistakably certain Suffioni and Lagoni waters of Middle Italy. Their degree of impregnation and their large proportion of chlorides bring them near the waters of Carlsbad and Franzensbad, Bohemia. The proportion of sodium chloride is not surprising in the American West, in the neighborhood of un-

drained and therefore salt regions, but it is surprising in Bohemia, a country notoriously free from salt, in which no rock is known to contain these highly soluble substances. We must assume that they exist in the deeper region, in forms not yet decomposed, such as sodalite ($3Na_2Al_2Si_2O_8 + 2NaCl$) which must be chemically decomposed before its NaCl can be dissolved. The presence of quantities of salt smaller than those here under consideration can be attributed (as I at one time attempted to show*) to atmospheric precipitation. A. Bobierre† found by careful and continuous analysis of the rain-water falling in Nantes throughout the year 1863, 14 grammes of salt per ton or cubic meter; and G. Zoppe‡ has argued that the sometimes considerable contents of sodium chloride in the springs of the Iglesiente district, in the island of Sardinia, can only be explained by the transportation of salt from the sea by wind. (A stormy cloud-burst, March 7, 1886, showed as much as 387 grammes per ton or cubic meter). The salt of the atmospheric precipitation is concentrated by evaporation. In Bohemia, for instance, only one-fourth of the rainfall escapes into the Elbe; in more southern regions the whole evaporates. The descending ground-water is still further concentrated; so that in this way the salt normally found in the ascending waters may be accounted for.

But while the water of Steamboat Springs is rich in sodium chloride, the Comstock mine-water is poor, notwithstanding the comparatively near neighborhood of the two places. Both adjoin eruptive rocks, especially basaltic outflows; but the Steamboat Springs break out of crystalline rocks. May not the ascending waters have derived their abundant sodium chloride from minerals, like sodalite, which contain it chemically bound?

Hydrogen sulphide plays an important part in the ascending waters. Its presence seems to be the cause of a greater abundance of dissolved substances. It is attributed to the decomposition of sulphates through the organic matter, traces of which are found in most of the ascending waters. By re-oxidation, it produces the sulphuric acid which transforms carbonates into sulphates. It is remarkable that in many mineral springs H_2S appears periodically in surprising excess, and often disappears again, almost without leaving

* "Zur Genesis der Salzablagerungen, besonders jener im nordam. Westen," *Kais. Akad d. Wissensch., Wien*, 1877.

† *Compt. rend.*, lviii., p. 755. *Bullet. Soc. Chim.*, 1864, *Nouvelle Série*, t. ii., p. 467.

‡ "Descrizione geologico-mineraria dell' Iglesiente," *Memorie descritt. della Carta geol. d'Italia*, iv, Roma, 1888, p. 119.

a trace. It is probable that an alternation of the processes of oxidation and reduction would produce this phenomenon.

The most important geological factor in ascending waters is undoubtedly carbonic acid; for it is chiefly this compound which in the deep region, under high temperature and pressure, develops a greater solvent power for most of the elements of the rocks. The alkalies, earths and silica of our mineral springs have certainly been dissolved from the rocks by carbonic acid, and the carbonates thus formed usually predominate over the associated sulphates. The analyses do not give us the conditions in which they exist, because the statements of results depend largely upon the individual views of the analysts.

The general exhibit sketched above shows that in the Comstock waters the sulphates exceed the carbonates; and that the chemists have been led to connect the sulphuric acid preferably with the earths. They have simply found an excess of sulphuric over carbonic acid, as is the case also in the strong thermal springs of Bohemia. The relation between the two analyses of Sulphur Bank water is remarkable; one showing the sulphates, and the other carbonates, to be predominant. Apparently one sample was taken from water which had been for a considerable period in contact with the atmosphere, so that the liberated H_2S gas, oxidizing to H_2SO_4, expelled the CO_2 from a part of the carbonates. The three irruptive thermal waters, Nos. 1, 2 and 3 in the table are acid, and also contain a notable quantity of free CO_2 in solution—which, indeed, determines their acid character. I have added for comparison Nos. 16 and 17, two favorite Bohemian acid springs. No. 18 is the famous Vichy spring in France; No. 16 is a weak water, esteemed for table-use; and No. 17 is the celebrated stronger water of Bilin. A few years ago, the quantity of the latter spring had seriously fallen off; and there is reason to surmise that a part of its water had found a way into the collieries of Brüx, where similar acid springs appear at several points. Fortunately for Bilin, an increased supply was obtained there by means of an adit and bore-hole. It is known that distilled water at normal barometric pressure and ordinary indoor temperature may contain in absorption an equal volume of carbonic acid, and that mineral water under the same conditions has a somewhat higher absorption-coefficient. The free CO_2, not held in bicarbonates, is mostly given by analysts in terms of weight. These, by the employment of the well-known volume of one gramme of CO_2, could be easily transferred into terms of volume, a more practical form for all cases, which is unfortunately not yet generally used.

Since in the deep regions the absorption-capacity of water for CO_2 is diminished by increased temperature, but, on the other hand, increased in much greater proportion by increase of pressure, a portion of the gas absorbed in depth is liberated in the higher region and contributes energy to the ascending current.

Thus far the substances present in mineral waters in the largest proportions have been chiefly considered. We must now study also those which occur in minute proportions, since these concern most nearly the question with which we are dealing.

Minute Metallic Admixtures in Mineral Waters.—Ordinary analyses show the presence of some metals, especially iron and manganese, which occur as easily oxidizable protoxides, giving rise to the precipitation of hydrated peroxides. Lime carbonate, in solution as bicarbonate, is simultaneously precipitated by evaporation and the loss of CO_2; and silica is likewise thrown down under certain conditions. Such precipitates are called, according to their predominant ingredients, ocher, sinter, tufa, travertine, etc.

Minute metallic admixtures are found:

1. Dissolved in the mineral water itself.

2. In the ochers or sinters deposited at the mouths of springs where they are concentrated in observable quantity, having been, without doubt, originally held in solution by the springs.

3. Moreover, there are found, in some places, at the mouths of springs, substances which were not originally in the solution, but have been subsequently dissolved and ultimately precipitated by the action of the mineral water upon various foreign bodies attacked by it.

The proportions of metallic ingredients found in ordinary spring-analyses were at first generally regarded with doubt, unless a chemist of the rank of Berzelius vouched for them. Fresenius and others admitted that such ingredients might be taken up from metallic conduits. But at last they were proved to exist in springs, excluding this hypothesis. Of course, "traces" are worthy of less confidence than ponderable quantities. According to Dr. Loschner,* Göttl found in the Giesshübl waters "traces" of copper, and even of gold. Of the fifty-nine chemical elements recognized in 1817, twenty-four were known to Elie de Beaumont† as occurring in mineral springs. Of these only six (Ur, Mn, Fe, Bi, Sb, As) were metals.

* *Badeschrift über Giesshübl*, 3 Aufl. Prag, 1855.

† *Bulletin de la Soc. Géol. de France*, 2 Sér., iv., p. 1249, etc.

G. Bischof* doubled this list, and the knowledge of the subject has been greatly increased since by Liebig, Will, Fresenius, Rammelsberg, Wackenroder, Thenard and Chevalier. It is chiefly from the deposits of springs that we learn of the minute metallic substances once dissolved in them. The oxides of Cu, Sn, Co, Zn, Sb, Ni, etc., were precipitated together with the oxide of iron. Ochers are especially rich in arsenic. Tin is often found in the thermal deposits of Wiesbaden, Soden, Homburg, Rippoldsau, Alexisbad, Driburg, Bruckenau, Kissingen, etc.

Lead occurs in the springs of Rippoldsau (according to Will, 1.6 to 3.7 milligrammes per ton), Kissingen (10 to 13 mg. per ton) Alexisbad, Ems, Homburg, Carlsbad (in the Schlossbrunn, according to Göttl), Pyrmont, etc.† Copper has long been known to exist in acid mine-waters (*e. g.*, the cement-waters of Schmöllnitz, Herrengrund in Hungary, etc.), and is found also in ascending waters at Carlsbad (authority, Göttl), Aachen (Liebig), Bagnères de Luchon (Filhol), Bourbonne (Tomsier), Luxeuil (Braconnot, Henry), Wiesbaden (Fresenius), Brückenau (Keller), Rippoldsau (Will), and in many other chalybeate waters.‡ Arsenic is, of course, often found in mineral waters. I will mention only the Magdalena spring of Mont-Dore (45 to 55 grammes per ton, says Thenard), St. Nectaire (6 to 8 per ton), Royat (35 g. per ton), and La Bourboule (815 g. per ton). G. Bischof§ gives as follows the maxima found in mineral springs up to 1854:

	Milligrammes per Ton.	
	Of Water.	Of Ocher.
Arsenious acid, ...	1.5	38.460
Antimony oxide, ...	0.1	.....
Zinc oxide (sulphate), ...	13.3	.....
Lead oxide, ...	0.1	1.900
Copper oxide, ...	6.4	1.000
Tin oxide, ...	0.1	.50

I add, as illustration, the contents of the mineral waters of two important localities, as calculated from the contents of the ocher. The chief constituents of these waters are given in the table on page 234. The first three springs are at Rippoldsau.

* *Lehrb. d. Chem. Geologie*, Aufl., i., p. 2078.

† Dr. B. M. Lersch, *Hydrochemie*, i, Berlin, 1864, p. 432.

‡ *Ibid.*, p. 438.

§ Dr. H. Ludwig's *Die natürlichen Wasser*. Erlangen, 1862, p. 96 Compare J. Roth's *Allgemeine und Chemische Geologie*, Berlin, 1879, p. 564, etc.

Locality:	Rippoldsau (acc. to Will.)	Kissingen (acc. to Keller.)			
Springs:	Josef.	Wenzel.	Leopold.	Pandur.	Rákoczy.
Constituents.	Milligrammes per ton.				
Protoxide of tin	25	17	38	134	166
Antimony oxide	16	10	24	107	134
Copper oxide	104	69	156	128	150
Arsenious acid	600	400	900	1120	800

In discussing Steamboat Springs I have already mentioned the metals found by G. F. Becker, among which are Hg, Au, and Ag.

I would only, in addition, call attention to the variations in the deposit of one and the same spring, for which purpose I select the Puits de l' Enclos des Celestins, at Vichy,* of which an analysis is given in the table on page 234. This contains in 1000 parts:

	Residuum obtained by evaporating the mineral water.	Ochreous deposit.	Calcareous deposit.
Alkaline carbonates,	735	.....	.....
Earthy carbonates,	129	169	980
Ferrous carbonates,	3	.....	.....
Manganous carbonates,	.....	.....	4
Iron oxide,	.....	474	10
Alkaline sulphates,	42	.....	.....
Chlorides,	72	.....	.....
Silica,	8	10	.....
Arsenic acid,	0.4	70	.....
Other constituents,	10.6	277	6
	1000.0	1000	1000

Alterations Produced by Mineral Springs.—Daubrée, in the chapters devoted to this subject, distinguishes the action of mineral waters upon the rock they traverse, and their action upon artificial substances which have found their way into the mineral water.†

a. Under the first head he cites alunite, kaolin, and serpentine as the result of mineral springs in general. I would call attention, however, to the circumstance, not yet sufficiently appreciated, that the rocks in the neighborhood of a mineral spring often have a very different appearance from those at a distance. In the case of springs carrying sulphuretted hydrogen, this is self-explanatory.

* Dr. H. Ludwig's *Die natürlichen Wasser*, Erlangen, 1862, p. 199.

† *Les eaux souterraines a l' époque actuelle*, ii., p. 67, and *Les eaux souterraines aux époques anciennes*, p. 178.

Sulphur Bank represents the phenomenon in a striking way as regards basalt. Granite is often decomposed in the neighborhood of springs,—as in the Carlsbad region, where some acid springs, like that of Giesshübl, emerging on the contact between granite and the overlying Tertiary rocks, have transformed the granite into kaolin. I have observed similar decomposition at the springs of Johannisbad, in Bohemia, and at many other places. It is to be regretted that these phenomena have been seldom studied, as yet, from a chemical standpoint.

Daubrée has pointed out the effect of mineral water upon various rocks and artificial building-materials in the masonry shafts of the springs at Plombières and Bourbonne-les-Bains;* for instance, the zeolites (chabazite, harmotome, christianite, mesotype, apophyllite) formed in the Roman béton; the hydrous silicates (plombierite, chalcedony, hyalite) in the Roman bricks at Plombières; recent formations of calcite and aragonite, and also the funnel-shaped cavities eaten out of the dressed limestone of the masonry. The latter are specially interesting as having been excavated from below upwards,—that is, in the direction of the ascending spring. Fig 9 illustrates this action upon such a building stone.

An analogous, and, for our purpose, still more important observation, was made in 1845, at Burtscheid, near Aachen, by J. Nöggerath. A terrace was constructed at that time in the neighborhood of the hot spring, as the site for a house. Blasting in the Devonian limestone exposed several vertical channels of nearly circular section and 20 to 90 centimeters (8 to 35 inches) diameter, some of which contained thermal water and emitted steam. They had been partly choked by rock-débris, but one of them showed a depth of about 4 metres (13 feet). Immediately around these tubes the elsewhere solid limestone had been altered for a distance of 15 centimeters (6 inches) to a gray, earthy mass, almost plastic when damp, and separable in thin scales. In places, this earthy mass had fallen away, and on the sides of the enlargements of the tube thus formed, crusts of white lime-sinter had been deposited.† Nöggerath does not doubt in the least that the mineral water emerged 5 to 6 metres (16 to 20 feet) above the present exit, and eroded the channel for itself. He believes even that the channels of all the mineral

* *Géologie Expérimentale*, p. 180.

† J. Nöggerath, "Ueber die sogenannten natürlichen Schächte oder geologischen Orgeln in verschiedenen Kalksteinbildungen." Karsten's *Archiv für Min., Geogn., Bergbau, u. Hüttenk.*, 1845, p. 513.

springs of Burtscheid and Aachen, which came from the limestone, have a similar shape.

He calls attention to the fact, observed by him and his friend G. Bischof, that the slabs of black marble covering the curbing of the Kaiserquelle, near Aachen, and the Schwerdbad, at Burtscheid, had been transformed by the constant action of the steam upon their inner surfaces into a doughy mass, which could be easily scratched away with the finger-nail.

Besides this evident action of thermal springs upon limestone, we may conclude from the foregoing that such waters, tending to an upward movement, may actually eat their way through limestone to the surface, or to rocks offering communication with the surface. This circumstance was not known to me when I published my monograph on the Rézbánya deposits,* in which I attributed to ground-water the erosion of the channels in the limestone which are filled with ore, instead of allowing them to have been formed by the ascending mineral waters.

The treatise of Nöggerath above cited contains also observations upon the analogy between the thermal-water channels of Burtscheid, the so-called "geological organ-pipes" (*les orgues géologiques*) in the chalk-deposits of Maestricht, and the "natural shafts" (*puits naturels*) in the Eocene limestone of the vicinity of Paris. The latter, however, have shown neither mineral water nor any traces of its former presence, and are of little interest for us. Recent investigations of both the phenomena referred to are unfortunately not now at hand.

b. Regarding the effects of mineral waters upon artificial products immersed in them, we are indebted to Daubrée for the preservation of numerous important observations in the masonry pits of the springs of Plombières and Bourbonne-les-Bains.†

The springs of Plombières occur in the neighborhood of ore-bearing quartz veins, and furnish at 68° C. a water rich in carbonic acid but poor in solid constituents, the residuum after evaporation being 400 grammes per ton (0.04 per cent.). Those of Bourbonne-les-Bains, on the other hand, have a temperature of 58° C., and are rich in mineral matter, the residuum being 7000 to 8000 grammes per ton (0.7 to 0.8 per cent), chiefly sodium chloride (5.800 grammes).

* *Geol.-mont. Studie der Erzlagerstätten von Rézbánya in S. O. Ungarn*, Budapest, 1874, p. 179.

† "Formation contemporaine de diverses espèces minerales cristallisés dans la source thermale de Bourbonne-les-Bains." *Annales des Mines*, 7 series, 1875, viii., p. 439. Also, the German edition of Daubrée's *Études synthétiques*, 1880, p. 57.

They flow from the variegated marls of the upper Trias, underlying the Muschelkalk, in the vicinity of large fault-fissures. Carbonic acid appears to be present in traces only, and the same is true of hydrogen sulphide, which is detected by its odor, and has given rise also to small deposits of sulphur.

In 1874, with the aid of powerful pumps, the abundant current of the spring was successfully overcome, and the foundation of the old Roman curbing was made accessible. The mineral water rises from horizontal clay beds through a funnel filled with sand, which scarcely represents the original channel. At the bottom of the masonry lining a clayey slime was encountered, in which, besides thousands of hazelnuts, acorns and fruit-seeds, many Gothic and Roman coins were found, with numerous other objects, such as bronze statuettes, needles, rings of electrum, pieces of leaden framing, etc. The gold coins weighed in all 25 grammes, the silver coins 625 grammes, but of the bronze coins there were 20,800 grammes, and many had disappeared entirely, leaving only their impress, and forming shapeless masses of the products of their decomposition, mixed with grains of sand. Of the minerals formed from the bronze, the greater part came from the copper (red copper-ore, copper-glance, chalcopyrite, peacock-ore, tetrahedrite, atacamite,) and only one from the tin—on a coin which still showed bronze in its interior, but was covered with a white layer of tin oxide. The action upon lead had produced coatings of galena and phosgenite, scales of lead oxide, and cerussite. Iron had not been altered to ordinary rust; the product of its oxidation contained silica. Moreover, pyrite, instead of the earthy black sulphide often occurring on the surface, had been formed from the iron, and was found covering pebbles and grains of quartz, angular fragments of sandstone, and also some evidently artificial products, such as flint knives—thus indicating indubitably its recent origin.

Strange to say, in spite of the quantity of chlorides in the water, and the great affinity of silver for sulphur, the silver coins had not been very seriously attacked, and their designs were still quite distinct, when they had not been coated with sulphides from the neighboring bronze coins. They must have been protected from chemical action by something not now determinable.

Moreover, iron and silica (or a hydrated silicate) had penetrated the wood found in the springs.

"At Bourbonne, as at Plombières, the intrusive formations are less than 8 meters (28 feet) below the surface; and yet they are very different from what we

are accustomed to see in our laboratories. A temperature was sufficient for them which is low in comparison with that which obtains at greater depths. What forces would we not see at work, if we were permitted to follow downward the channels which have been the pathway of hot springs!"—Daubrée, *op. cit.*, p. 91.

Structural Features of the Deposits of Mineral Springs.—The original conditions at the point of outflow of mineral springs have seldom been preserved intact. Even when their channels have been successfully prolonged through the ground-water to the surface, erosion, on the one hand, has partially removed them (since they often emerge in valley-bottoms), or human agency on the other hand, has variously disturbed them by diverting, choking, or walling them, or by the erection of buildings with foundations. For our purpose it is important to be able to show that, in all channels extending to the surface and still uninjured, a regular filling with symmetrically arranged mineral crusts may be observed.

Such a regular filling of the fissure-channel of a spring I have seen at the tufa mounds of the Bad of Arczó near Parajd in Transylvania.* The filling of a fissure 25 centimeters (10 inches) in width consists of variegated crusts of aragonite, as thin as paper, the fibers of which are perpendicular to the walls of the channel. The latest crusts are darker, and give a bituminous odor when dissolved in hydrochloric acid; the oldest are usually milky white, and leave after similar treatment a residuum of gelatinous silica. The water tastes very unpleasantly salt and bitter. The gas which hisses from the depths of the fissure is doubtless mainly carbonic acid, perhaps with an admixture of hydro-carbon.

Since the drawing of the mouths of Steamboat Springs given by Le Conte (*op. cit.*, p. 425) may not be entirely comprehensible, I introduce in Fig. 8 an ideal section of one of the spring-mounds of Arczó.

It is only the channel which is filled with solid, almost transparent crusts; the deposits on the side of the mound are a fine-grained, white lime mass, and in the less immediate vicinity of the springs there are in many places horizontal layers of a lime tufa, containing plant-remains.

Pigeon and Voisin describe an analogous but much larger phenomenon in Vichy, at the *rocher des Célestins*, where an almost ver-

* F. Pošepný. "Studien aus dem Salinengebiet Siebenbürgens," *Jahrb. d. k. k. geol. Reichsanstalt*, Vienna, 1867, xvii, p. 477.

tical aragonite filling, 2 meters (6.5 feet) wide and 200 meters (650 feet) long, with fibers perpendicular to the planes of the crusts, may be observed (Daubrée, *op. cit*, p. 159).

The waters flowing away from mineral springs likewise make solid deposits, which often form horizontal layers, covering considerable areas. These are the so-called travertines—formations analogous to the Carlsbad *Sprudel-* or *Erbsenstein*, etc. But we are concerned at this point with the deposits in the spring-channel itself and in its immediate vicinity, including not merely the crusts upon the walls proper, but also those surrounding large or small fragments of rock within the channel. Many such deposits are characterized by the pisolite formation, which we may observe also in ore-deposits (concretionary iron-ores, etc.). These pisolites are evidently incrusted kernels, the crusts being proportionately much thicker than the kernels. The Carlsbad *Sprudelstein* shows, indeed, the same structure on a small scale as many ore-deposits exhibit on a large scale. The pisolites, like those of Tivoli and Hammam Meskoutine, consist of lime carbonate, pure or slightly intermixed with iron oxide and silica. At the last-named locality pyrite occurs between the layers of carbonate, so that the formation must be pronounced to be crusts of lime carbonate and pyrite upon a foreign nucleus, which was elevated and incrusted so long as the ascending column of the spring had energy enough to move it.

A few words may be well added here concerning the Carlsbad *Sprudelschale* and *Erbsenstein*. As is well known, the *Sprudel* represents an action like that of geysers, ejecting thermal water and steam to a considerable height. The precipitate at the present time is a porous, somewhat ferruginous aragonite or travertine mass. The ground from which the *Sprudel* breaks forth is composed of horizontal layers of a much denser aragonite mass, which can be polished, and furnishes material for artistic lapidary-work. A part of the town of Carlsbad stands on this so-called *Sprudelschale*, from which new thermal springs sometimes break out, and the structural history of which may have been like that of the rising succession of basins at the Mammoth Hot Springs of Gardiner river, in the Yellowstone National Park.

Certain layers of this *Sprudel*-deposit are exclusively aggregates of pisolites of pea-size, whence the name *Erbsenstein* (pea-stone). Evidently these have been formed, like those of the Hammam Meskoutine spring, immediately at the outflow of the mineral water. The precipitate from the solution (at the moment supersaturated) was de-

posited around individual rock-grains, which had found their way into the spring, to be for awhile kept in motion by its current. Successive crusts were thus deposited, until the pisolite became too large to follow the movement of the spring and sank to the bottom, where its accessible surfaces received still further precipitate-crusts. It might easily occur, that single cavities might remain, into which the precipitate could not penetrate. These would represent, according to our terminology, the central druse. Fig. 12 illustrates this process, while Fig. 13 shows a single pisolite, including pyrite-crusts, from Hammam Meskoutine.

I have had opportunity to see a completely analogous result produced by falling drops at Offenbánya, where, at certain points in an adit abandoned for some thirty years, water rich in lime carbonate trickled from the roof, forming upon the floor a deposit several centimeters thick. At the spot where the drops fell directly upon the floor, a small basin-like depression was formed, in which lay, like eggs in a birds' nest, various bodies like pisolites, consisting of a sand-grain at the center, surrounded by concentric crusts of carbonate. Some of these formations lying in the middle of the nest were quite loose, so that they were turned over by the force of the falling drops, which explained the tolerably uniform incrustation upon them. Others situated near the edge were already fixed, could not move any longer, and showed at points a deposit of sinter* (Figs. 14 and 15). Similar formations, known as "birds' nests," are described by Schmidt in the old mine-workings of Riegelsdorf and Bieber.† Such formations appear to be by no means rare in metal-mines. I found, for instance, in Offenbánya at the face of a level which had been abandoned for some years, that small chips of rock had been covered by the falling drops with two separate thin crusts: first, a white lustrous smithsonite, and thereupon a black, easily-detached crust of a maganiferous substance.‡ (Fig. 16). The pisolitic bodies formed by falling drops are not easily confounded with those formed by a flowing spring, and when such are found in the interior of an ore-filling, they cannot well be ascribed to drippings.

Pisolitic forms appear in many ore-deposits. Thus the calamine-deposit of Santander in Spain betrays an oölitic structure, and I have observed in the gold mines of Verespatak, pisolitic forms, the

* F. Pošepný, "Ueber concentrisch-schalige Mineralbildungen," *Kais. Akad. d. Wissensch.*, Vienna, 1868.

† *Beiträge zu der Lehre von den Gängen*, p. 42.

‡ See my paper on crustified mineral formations, cited above.

kernel being an aggregation of gold, and the surrounding thin crusts, carbonates of lime, manganese and iron. To this subject I shall recur.

From what has been said concerning the structural relations of mineral-spring deposits, it appears that at the mouths of such springs phenomena are shown, such as crustifications of wall-deposits, pisolitic forms, etc., which we meet frequently in ore-deposits also—an additional reason for declaring the latter to have been formed by mineral springs.

5. Origin of Ore-Deposits in the Deep Region.

We have seen that the mineral springs which ascend to the surface are dilute metallic solutions, and that at their outflow (the only point where we can directly observe their activity) they form deposits, containing metals, among other things, and exhibiting a structure which occurs in ore-deposits likewise. We have followed to a not inconsiderable depth one ore-deposit which occurs upon an ascending spring, and have found that, apart from changes conditioned by the vicinity of the surface, it continues its character. Finally, we have encountered mineral springs in many places where mining has followed ore-deposits in depth. Joining these several links of observation, we cannot avoid the conclusion that the ore-deposits found in the deep region are the products of mineral springs, the more so since many of them have a structure and form which can only be explained as the result of precipitation from liquids circulating in channels. The deposits from these liquids contain substances which are foreign to the surface and to the shallow region, and hence could not have been brought into circulation by the descending ground-water, but must have come from a deep region, where higher temperature and pressure (the two factors increasing the solubility of all substances) exist.

Comparing the average density of the earth (which is, according to the very recent and careful investigations of R. von Sterneck,* 5.6) with the average density, 2.5, of the rocks forming the earth's crust, we must admit that in the central mass substances much denser than 5.6 have been accumulated, that is to say, the deep region is the peculiar home of the heavy metals.

If we imagine ourselves standing in the deep region in front of

* I would call attention to the labors of v. Sterneck, pursued upon this point for a decade, and described in the *Mittheilungen des k. k. Militär. Geograph. Institutes*, in Vienna.

the profile of an ore-lode, like the Adalbert at Przibram, for instance, 1110 m. (3600 feet) below the surface and 564 m. (1850 feet) below sea-level, we perceive a fissure-space of discission, filled with symmetric mineral crusts, chiefly argentiferous lead sulphide. Remembering that this filling has been stoped continuously to the surface, we can find no other satisfactory explanation than the hypothesis that it was brought up from still greater depths, and, in view of the comparative insolubility and the large quantity of the metallic sulphide here accumulated, it must have been deposited from perpetually renewed, and, therefore, from *ascending*, mineral solutions. Whoever has had opportunity to study an ore-lode in the deep regions can conceive no other explanation. The miners themselves have always held this opinion; in other words, they have all been *ascensionists*. In the case of ore-deposits occupying tubular channels in soluble rocks, the origin of these spaces is not at once clear; and it has thus happened that one or another observer, misunderstanding the analogy of the substance and the conditions of filling, has suggested a different hypothesis, as, for instance, S. F. Emmons, whose conclusions as to the Leadville deposits I shall take the liberty of controverting in a later part of the present paper. I do not deny that there are ore-deposits permitting such a different explanation, but they occur in the shallow region only, and not in the deep region.

In the two groups of ore-deposits already discussed, and formed in pre-existing spaces, a distinct crustification leaves no doubt as to the manner of filling. Where crustification is obscure or absent, it is indeed not possible at once to offer this convincing proof of the manner of deposition. Recourse must then be had to the analogy of the substances and their paragenesis. If these correspond with the contents of spaces filled with crusted deposits, a similar origin must be inferred; that is to say, even in cases in which mineral solutions, ascending from the deep region, found no open, continuous channels, but were forced to create the necessary space by the removal of a previously-existing material, the conditions of the deep circulation still controlled. From these considerations it follows that all the deposits of the deep region are referable to one general ruling process, clearly shown to be the action of ascending mineral solutions; that is, they were all formed by ascension.

This conception is diametrically opposed to the view recently suggested by Dr. F. Sandberger, that ore-deposits are formed by so-called lateral secretion. This view was at first asserted to be

universally applicable. Afterwards, the author characterized it as holding good for the majority of ore-veins only, and restricted it by the following definition:

"The theory of lateral secretion was conceived in this sense only, that the material for the filling of veins is derived from the country-rock through gradual leaching by seepage-water (Sickerwasser), which brings the dissolved substance from both sides to the vein-fissure, where it is then converted by chemical decompositions into insoluble gangue-minerals and ores, and so deposited."*

It will be seen that he started from the wholly erroneous assumption that the ore-veins of the deep region stood open (like the fissures in a rock upon the surface), so that seepage-water from both sides could deposit material in them. That is, he conceived of a fissure containing air only, and forgot entirely that such open fissures are found exclusively above the ground-water level, below which every newly-formed fissure must be immediately filled with water. The term *sickern* corresponds with the English "seep," "trickle," or "drop," and can only be understood as describing the downward movement of a small quantity of liquid. It is thus impossible to suppose that Sandberger's meaning has been misunderstood; and we are forced to conclude that he boldly extended his conclusions to cover a region with the physical conditions of which he was unacquainted.

A lateral secretion in this sense is, as I have elsewhere shown,† possible above the ground-water level only. It is indeed conceivable that even in the deep region isolated spaces may exist, from which accumulated gases find no way to the surface, and in which formations may occur, similar to those in cavities above water-level; but such instances (as at Wiesloch, in Baden, and Raibl, in Carinthia) are demonstrably exceptions to the general rule above stated.

What interests us most is, that in order to establish his theory, Sandberger was forced to discredit the fact of actual deposition in the channels of mineral springs. The proof of this fact at Sulphur Bank and Steamboat Springs was highly inconvenient. Since, as he had said, "waters which flow with such rapidity as that of ascending mineral springs containing carbonic acid are shown by experience to produce no deposits in their channels, but to do this

* F. Sandberger, *Untersuchungen über Erzgänge*, 2tes Heft, Wiesbaden, 1885, p. 159.

† "Ueber die Bewegungsrichtung der unterirdisch circulirenden Flüssigkeiten." —*Compte rend. de la 3me. session du Congrès géol. internat.*, Berlin, 1885.

only in the immediate vicinity of their outflow" (*op. cit.*, p. 5), he was not convinced by the conditions shown at Steamboat Springs, where the deposits are near the outflow. With regard to Sulphur Bank, he was not acquainted with the works of Le Conte and G. F. Becker, showing that the ore-deposit is found in the channel itself. Although he did not doubt "that ore-deposits are here observed in process of formation" (*op. c.*, p. 13), he recalled the well-known solubility of mercury sulphide in alkaline sulphides; argued that "the leaching of pre-existing quicksilver-deposits by alkaline sulphides presents no difficulty" (*op. c.*, p. 15); and was inclined to believe that the cinnabar-deposits near the outflow were referable to older ones. Endeavoring thus to render harmless the two instances unfavorable to the lateral-secretion theory, he summed up his consideration of them at that time with the remark that "in California no proof is presented of the formation of ore-veins by ascending springs" (*op. cit.*, p. 16). After reading Le Conte's account he returned to the subject in the second part of his work,* asserting (p. 162) that in the numerous excavations connected with the walling-in of mineral springs, it has never been observed that hot springs have deposited "metals" in the immediate vicinity of their channels. He confesses again (p. 161) that here is "unquestionably an ore-deposit, formed by the precipitation of silica and cinnabar from a hot alkaline sulphur-spring, which has found and dissolved mercury sulphide somewhere below;" and admits that hot alkaline sulphur-waters may precipitate, besides quicksilver, also gold, tin, bismuth, arsenic, and antimony,—but not copper, silver, and lead-ores, which are often associated with the foregoing. These, he says, cannot have been deposited from hot alkaline sulphur-springs. "There is, therefore (p. 162), no reason in the conditions of Sulphur Bank for restoring the ascension theory to its former authority in the science of ore-veins."

It will be seen that his chief argument is, that according to his opinion, no metallic deposit has ever been found in the channel of a spring, for he seems not to consider as conclusive the deeper workings at Sulphur Bank. Such a sweeping assertion is easy; for it is not likely that in walling a mineral spring excavations will be carried deep enough to reveal the condition of its channel proper.

Sandberger's contention comprises two propositions: (1) Metals

* *Untersuchungen über Erzgänge*, Wiesbaden, first part, 1882; second part, 1885.

have been found hitherto only in the ochreous deposits from mineral springs; and (2) in walling mineral springs, deposits formed in their channels have not yet been found. These two assertions are not controverted; but the conclusion, that because hitherto, in digging out mineral springs, we have found no metals in their channels, therefore they cannot be deposited in the channels, but only at the outflow, is illogical.

Excavations for the walling of mineral springs do not extend to the channels of the deep region. Heavy pumping is required to penetrate even a few meters below the ground-water level; whereas, to decide this question, a depth must be reached at which the ascending spring is not altered by the descending ground-water, the oxidation and chlorination due to surface agencies no longer appear, etc.

We know that temperature and pressure, the two great factors of solubility, are continually diminished as the surface is approached; and we can directly observe one result of this change in the liberation of the carbonic acid absorbed at greater depths. Why should not the substances rendered insoluble by the decrease of these factors be deposited in the channels? If no such deposition has occurred, then the precipitates must have been carried upward by the current, and should be separable by filtration from the water. G. F. Becker, in filtering the Steamboat Springs water before analysis, found (*op. c.*, p. 346) in the filtrate a precipitate of antimony and arsenic sulphides, with silica, which he ascribes to the fall of temperature and the action of low forms of plant-life.

But we find in various closed conduits of mineral water—*i.e.*, in artificial channels—that deposits are formed, not only at the mouth, but also in the channel itself. Why should natural channels form an exception?

I think it has been shown that Dr. Sandberger's chief objection to the formation of ore-deposits by ascending mineral springs is without foundation, and that the entire chain of phenomena corroborates our explanation. But the lateral-secretion theory of Sandberger suffers from several other fundamental defects, which I cannot avoid indicating in this place, because that theory was for a while accepted as a simple and welcome explanation of the genesis of ore-deposits, and began to hinder the progress of knowledge on that subject.

It found many disciples, especially among mineralogists, because it permitted the most extensive genetic generalizations, without

requiring the observer to leave his mineral collection and laboratory, to descend into the mine, and to study the ore in the place of its origin. On the other hand, it must be confessed that the promulgation of this theory led to many investigations of rocks, which will be useful to science in other directions.

Sandberger, being convinced that he had detected foreign admixtures of the metals in silicates, felt himself warranted in explaining by his theory all ore-deposits in the silicate rocks; but he could not so well deal with those in limestone, which were cited by Stelzner as a chief argument against the universality of his conclusion.* With regard to Raibl, in Carinthia, it occurred to him to examine the marly slates (*Mergelschiefer*) overlying the limestone; and finding in these, besides traces of Li, Cr, and Cu, more considerable quantities of Pb and Zn, he concluded that the metals in the ore-channels of the limestone under these slates had been leached out of the latter (*op. cit.*, p. 34). This was already a descending, and not a lateral secretion.

In a paper upon the applicability to this case of the lateral-secretion theory,† however, I pointed out that also below the ore-bearing limestone of Raibl, at Kaltwasser, there are silicate rocks, which probably contain likewise minute quantities of metal, and that if Sandberger had successfully analyzed these, he would have been obliged to assume an ascent. In the same paper, I argued that the lateral-secretion theory does not account for the sulphur and the metallic sulphides; and I brought forward for discussion the veins of Przibram, assuming that in that district, where sedimentary rocks are traversed by heavy eruptive masses, Sandberger could consider the latter only as the original source of the metals in the veins. From average analyses for the latest year of production, I calculated that each square meter (10.75 square feet) of vein-surface stoped represented 190 kilogrammes (264 lbs.) of metallic sulphides, or in detail:

	Pb.	Zn.	Fe.	Cu.	Ag.	S.	Sb.	As.
Kilogrammes,	132	13	5	0.3	0.8	34.6	2.5	1.7

If these substances had been derived by lateral secretion from the country-rock (the eruptive mass being 30 meters thick by the main vein, or 100 meters for the whole group of veins) there must needs have been in each cubic meter (35 cubic feet) of the country-rock

* A. Stelzner, *Jahrb. f. Min.*, 1881, p. 209.

† *Oester. Zeitsch. f. B. u. H.*, 1882, xxx., p. 607.

1.9 to 6.3 kilogrammes (4 to 18 pounds) of metallic ingredients—a quantity not to be called minute. Or, reversing the calculation, and starting with the largest proportion of metal ever found in these eruptive rocks, it would have required more than one hundred times the thickness of such rocks actually present in the district to supply the contents of the veins. By these calculations and other arguments, I showed, as I thought, the special inapplicability of the theory to Przibram, but I expressed a willingness to examine some of the eruptive dikes for minute metallic admixtures, preferring only that such an examination should be checked by another person.

The management of the government mining department entrusted to the chemist, A. Patera, the investigation of individual samples of Przibram rock, but also called Dr. F. Sandberger to Przibram, where the first tests were executed with the aid of a Commission, of which I was a member.*

Unfortunately an ailment of the eyes forced me to inactivity, and I could do little on the Commission.

Dr. Sandberger submitted a statement (*op. cit.*, pp. 305-327) or compilation, from which it appeared that he attached less importance to the analysis of the eruptive rocks than to that of the stratified rocks, composed of the detritus of the central Bohemian gneiss mass. According to this view, the metals of the Przibram veins came from the mica of the gneiss detritus. According to Dr. Sandberger, however, (*op. cit.*, pp. 362–3,) the investigation disclosed that "an essential part of the lead and silver contents of the ore-veins is due to the eruptive rocks"—which involves a modification of the above theory.

Twenty-five rock-samples, selected by the Commission, were tested for metallic admixtures according to a method agreed upon (but not very strictly followed) by Dr. Sandberger, H. Freiherr von Foullon, A. Patera and C. Mann, with tolerably concordant results, although Patera in particular expressed some doubts as to the correctness of the method. This led Prof. A. Stelzner in Freiberg† to make a thorough test of the means employed, which showed that Sandberger's method cannot decisively determine whether the

* "Untersuchungen von Nebengesteinen der Przibramer Gänge mit Rücksicht auf die Lateralsecretionstheorie des Professors Dr. F. V. Sandberger, ausgeführt 1884–7 und veröffentlicht im Auftrage Seiner Excellenz des k. k. Ackerbauministers J. Grafen von Falkenhayn."—*Jahrb. d. k. k. Bergakad.*, etc. xxxv., 1887, p. 299.

† A. Stelzner, "Die Lateralsecretionstheorie und ihre Bedeutung für das Przibramer Ganggebiet."—*Jahrbuch der k. k. Bergakad.*, 1889, p. 1.

metals detected in the silicate were original constituents, or whether they are not secondary impregnations, left undissolved by the reagents employed.

It is thus rendered probable that minute metallic admixtures detected in the country-rock by Sandberger's method are really derived from the ore-deposit, *i.e.*, are not idiogenous but xenogenous. His assumptions in this field also are thus shown to be indefensible.

While I acknowledge fully the great importance of chemical data for the explanation of vein-phenomena, I cannot give here, without becoming too prolix, all the chemical views, often quite discordant, and must content myself with the description of a theory of ore-deposits based upon purely chemical grounds, which has just been made public by De Launay. The author starts chiefly from the views of Elie de Beaumont* concerning volcanic and metallic emanations, adding to these the results of the studies of Fouqué, Senarmont, Ebelmen, St. Claire Deville, Daubrée, etc. He begins with the primitive occurrence of magnetite in the eruptive rocks, which he extends to many other metals and minerals whose primitive presence in eruptives has not been demonstrated. Certain metallic substances were segregated in cooling from the molten mass; others have been dissolved from the eruptive rock in depth by "mineralizers," such as emanations of chlorine, fluorine, sulphur, etc., and have been deposited in the channels leading to the surface. De Launay is a very positive ascensionist; he also doubts the primitive deposition of ores in marine basins, and thus comes by the path of chemical speculation to results analogous to mine. Volcanic and ancient eruptive rocks; fumaroles and mofettes; geysers and thermal springs—these indicate the ways by which the metals have reached the earth's surface. But of such assumptions we must obtain assurance through observations in other directions. Views based upon purely chemical conclusions are not sufficiently convincing for us, because they are gained in the chemical laboratory under conditions different, especially as to pressure and temperature, from those which obtain in the deep region.

Manner of Filling of Open Spaces in General.

We know already that cavities, however originated, are always filled in analogous ways. We find in vein-spaces, in the spaces of

* Elie de Beaumont, *Bulletin de la Soc. Géol. de France*, 2 sér., iv., p. 1249.

dissolution, and even in individual geodes of opal and chalcedony, always the same elements of structure, though in the most widely different materials.

Considering the matter closely, we find that many things are peculiar to the shallow region, as the nearest to atmospheric influences; but some things experienced in that region may be used to explain the phenomena of deposits in the deep region also.

Since we have seen that the precipitate in an approximately horizontal pipe, entirely filled with liquid, attaches itself to the whole interior surface, the same must be true for an underground channel, and all the more if it approaches a vertical position. Under such circumstances the deposit or mineral crust will cover uniformly the whole wall-surface.

Evidently the same laws govern here as in sedimentation. When the section of the passage through which the liquid flows under a given pressure is relatively small, the deposit will take place only when the passage is enlarged. This explains the sometimes unequal distribution of ore in one and the same mineral-water channel.

As in a saturated solution a precipitate may be obtained upon any solid body introduced, so in our mineral-water channels deposits will be made upon all solid bodies—splinters or masses of rock fallen into the fissure, loose pieces of older mineral crusts, and individual crystals floating in the liquid.

The size of the rock-fragments here considered is very variable. We might include, for instance, those which are inclosed between two regular vein-branches. But we will narrow our view to what can be seen from a single standpoint in the mine, and then we observe that horses of several square meters' surface are uniformly crusted, like small pieces of country-rock found in the vein-filling, the only difference being, perhaps, that the crusts are thicker and more numerous upon the larger masses. The fragments of rock, either angular or already more or less rounded, form, when incrusted, the so-called sphere-, cocarde-, or ring-ores. Crusted rock-kernels may often be observed coexisting with distinct wall-crusts. Sometimes the latter are less prominent than the former, and the ore-deposit then has the appearance of a breccia or a conglomerate, the several fragments of which are held together by the mineral crusts. If, on the plane of a given section, there appear no points of contact between the fragments, it must not be concluded that they originally hung free in the vein-space, or that they have been pressed apart at a later period by the force of crystallization of the mineral crusts,

for the actual points of contact can be found in a parallel section; at least, I have always found them when I have sliced into plates a specimen on the surface of which they were not shown. I mention this circumstance because many extensive discussions have been based upon imperfect views of single sections, giving deceptive indications of structure.*

I would recommend the frequent preparation of sections and slides of such apparently complicated structures, and I am convinced that seeming contradictions and difficulties would be simply explained thereby. It is only a question of correct observation and representation, for which, it must be confessed, the use of coloring may be necessary. In this connection I must remark that illustrations, erroneous in this respect, have found their way even into text-books, as, for instance, the picture of cocarde-ore given by Cotta,† which is taken from a careful but uncolored drawing by Weissenbach,‡ of which I reproduce a part in Fig. 17. Fragments of mica-slate are crusted with layers of quartz and pyrite, and in the vugs there is sometimes also manganese or brown-spar. The radial appearance of the crusts in the drawing is evidently due to the position of the crystals perpendicular to the wall-surfaces, and is, as a rule, observable in all such cases. The same figure from Weissenbach has been used by A. Daubrée also§, as an instance of a *filon brècheform;* but the several crusted rock-fragments are separated by heavy lines, which make the representation not only incorrect but incomprehensible.

The phenomenon may be most generally illustrated by Fig. 18, which represents a section through a gold-specimen from the Katrontza ore-body at Verespatak, and of which I intend to publish in my monograph on the occurrence of gold in Transylvania a series of parallel sections in color. Four pebbles, three of quartz-porphyry and one of mica-slate, are regularly crusted with (1) a thin zone of hornstone, (2) a thin crust of pyrite, composed of several layers no thicker than paper, (3) hornstone, in which occurs (4) a zone, 5 mm. (0.2 in.) in average thickness, of fine aggregates of native gold, extending often into the next following crust (5) of quartz, containing

* *E.g., Trans. A. I. M. E.*, 1883, xi, 119.

† *Lehre von den Erzlagerstätten*, Part I., Freiberg, 1859, p. 33.

‡ C. G. A. von Weissenbach. *Abbildung merkwürdiger Gangverhältnisse*, Leipzig. 1836, Fig. 2.

§ A. Daubrée. *Les eaux souterraines aux époques anciennes*, Paris, 1887, Fig. 24, p. 64.

scattered clouds of hornstone. The series ends in this specimen (6) with open central druses. But other specimens from the same deposit show also minute crusts of manganese-spar, to which I shall recur.

Fig. 11, representing the occurrence of cinnabar in the deeper workings at Sulphur Bank, is an interpretation of the description and sketch given by Le Conte (*op. cit.*, p. 28). Fragments of sandstone and slate with somewhat rounded edges are regularly surrounded with crusts of cinnabar which fill the space between, up to the central druse. Sometimes crusts of hydrated silica and pyrite appear also. Fig. 10 is a picture of a rich portion of the surface-workings of 1874, which I sketched at that time in my note-book. The basaltic country-rock is thoroughly cut up by irregular seams, which have disintegrated it to a shaly mass. In the seams, especially where they come together, larger spaces have been formed, often filled with decomposed country-rock, often showing separate crusts of cinnabar and opal, with a central druse. The porous material of rock and filling is impregnated with native sulphur.

Fig. 19 shows the filling of a space of dissolution at Raibl. It is a diagram from the accurate picture in my monograph upon the deposit.* A nucleus of limestone is surrounded by innumerable fine crusts of wurtzite and more compact but less regular layers of galena.

Fragments of earlier mineral crusts, which have been in some way separated from their original position, are often found surrounded by mineral crusts of later origin. An example is shown in Fig. 20, representing boiler-scale from one of the Przibram pumping plants. Here fragments of dislocated scale, about 2 mm. (0.08 inch) in diameter, are enveloped in later, thin crusts, and thus united to a breccia. The mass consists chiefly of fibrous gypsum, the fibers of which stand perpendicular to the surfaces to which they are attached.

Figs. 21 and 22 present a very distinct example, in which earlier mineral crusts, together with adhering pieces of country-rock, are surrounded by recent crusts. These figures are taken from the valuable treatise of J. C. L. Schmidt,† and refer to Zellerfeld in the Hartz,

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* "Die Blei-und Galmei-Erzlagerstätten von Raibl in Kärnthen."—*Jahrb. d. k. k. geol. Reichsanst*, xxiii., 1873, Bd. I., Fig. 13.

† Johann Christian Lebrecht Schmidt.—*Beiträge zu der Lehre von den Gängen*, Siegen, 1827.

whence A. von Groddeck also has obtained very interesting illustrations of vein-filling.*

I have seen a more complicated example from the Katrontza ore-body at Verespatak, where very rough ancient crusts of black hornstone and parti-colored quartz have been cemented together by deposits of later quartz and manganese spar to a compact mass, with some central druses. Similar conditions will be seen to obtain in the so-called pipe-ores of Raibl, Figs. 25 to 28.

The variable relation between the diameter of the nucleus and the thickness of the surrounding crust naturally contributes greatly to the variety of the resulting appearances. In the pisolitic formation, for instance, the crust is many times thicker than the nucleus.

In some cases the kernels are individual crystals. J. Ch. L. Schmidt describes pisolitic forms from Warstein, in Westphalia, the kernel of which is a crystal of yellow eisenkiesel, about 5 mm. (0.2 inch) in diameter, showing prismatic and dihexahedric faces, and covered first with a thin, white coating, upon which are crusts of coarsely fibrous eisenkiesel. The edges of these are gradually rounded, until egg-shaped spheroids, about 12 mm. (0.5 in.) in diameter, are formed, touching each other at single points, and leaving interspaces, which are either filled entirely with granular eisenkiesel, or contain residual vugs lined with transparent, finely crystalline quartz.

Fig. 24 represents the geologically important occurrence of crusted kernels of native gold from the Mátyas Kiraly mine at Verespatak. Minute aggregates of native gold are systematically surrounded by distinct, beautifully pink to carmine, thin crusts of rhodonite or rhodochrosite. So long as the kernels were completely separated, or were kept suspended by the disturbance traversing the cavity, these crusts were deposited entirely around each. After they had become fixed, later deposits of the same sort covered them; then followed carbonates of lime and iron; and finally came the quartz, the beautiful water-clear crystal-tips of which project into the central druses.

The occurrence of gold in manganese spar is not rare at Verespatak; ornaments cut from this material are pretty widely sold. But I have found but once such a distinct envelopment of the gold by the rhodochrosite crusts. The figure represents a piece cut for a brooch, which is in my wife's possession. It is specially interesting, also, as showing that the gold was not derived from the secondary

* A. von Groddeck.—*Ueber die Erzgänge des nordwestlichen Oberharzes.* (Inaugural dissertation) Berlin, 1867.

decomposition of auriferous sulphides or tellurides *in loco*, but was directly precipitated from the mineral solutions which subsequently deposited the surrounding crusts.

We have seen that within the domain of vadose or shallow circulation peculiar deposits, classed as stalactites, are very common, not only in the spaces eroded by the natural circulation of the ground-water, but also in spaces created through the artificial depression of the water-level by mining. In the latter case, since mining often follows ore-deposits into the deep region, a much larger variety of substances is exposed to alteration, so that stalactitic formations of all kinds of materials may be encountered. Chiefly, however, we find in this form the results of oxidation, and it is somewhat exceptional to meet with the products of reduction, effected by organic matter in the mine. The most frequent of these are stalactites of pyrite.

This circumstance led to the opinion that stalactites in an ore-deposit should be taken as characteristic of a vadose or shallow origin, through the descending movement of the solutions which formed the stalactites. This view has been most clearly advanced by Dr. A. Schmidt.* The earliest formations in the instructive Wiesloch deposits are the sulphides, marcasite, galena and wurtzite, to the decomposition of the latter of which, through the metasomatic replacement of the carbonate of lime by the carbonate of zinc, the zinc-ore deposits are due. These he held to be clearly vadose in origin; and since the sulphides also occur in stalactites, he concluded that they likewise must have been formed by infiltration from above. The fact that these latter formations now lie below water-level, whereas the formation of stalactites requires a space filled with air or gas, only forced him to endeavor to explain this contradiction by the hypothesis of suitable elevations and depressions either of the water-level or of the land itself.

But all this would have been unnecessary if he had borne in mind that ascending liquids under a certain pressure will penetrate into a cavity from all sides, and may enter through the roof if the bottom and walls are less permeable. He distinguishes in general two forms of development in the original ore-deposition, namely, the filling of the lower part of a cavity with nearly horizontal, undulating crusts of wurtzite, with a little galena, and the stalactites which hang from the roof, there being no discoverable trace of corresponding stalagmites below. This indicates that the cavity was not

* *Die Zinkerzlagerstätten von Wiesloch in Baden*, Heidelberg, 1881, p. 94.

wholly filled with gas, but only in its upper part, to which, consequently, the stalactitic forms are confined. As to the manner of the later decomposition of the wurtzite, which extends down to the present water-level, there can be no doubt (*op. cit.*, p. 101).

Similar conditions are found in Raibl, where I have carefully studied the stalactites locally called "pipe-ores."* I find these, it is true, not in their original position at the roof of the cavities, but in the midst of the filling, already broken off and surrounded by the latest mineral crust, in a dolomite spar. They seem to have occurred at many points in this deposit, but my observations were confined to two, one of which was on the 5th Johanni level, about 400 meters (1312 feet) above the deepest adit (the bottom of the valley), while the other was on the 7th deep level, about 60 meters (196 feet) below the said adit. The former of these two points was within the influence of the ground-water.

Under the conditions, decomposition of pyrite and zinc-blende had been specially great; that of galena less so. It was often possible to extract from the dolomite mass the stems of galena which were loose in it. The axis of such a stalactite-stem (frequently over 10 centimeters—4 inches—long) was often an open space through which one could blow air, whence the name "pipe-ore" given to this surprising occurrence. Specimens not decomposed or in early stages of alteration showed, besides galena, crusts of pyrite and zinc-blende, concentrically disposed around the axis.

Figs. 25, 26, 27 and 28 (taken from my former treatise) and representing sections of individual stalactites, are intended to cover the variety of forms in these occurrences. Fig. 25 shows a circular stalactite in which small quantities of galena may be seen in the pyrite surrounding the axial cavity. The outer crust consists of thin layers of wurtzite (*Schalenblende*). In Fig. 27 a galena mass of rhombic section, with regular striations of secretion, sits immediately on the side of the cavity. In Fig. 26 the annular mass of galena is surrounded by blende. In Fig. 28 a decomposed body of blende lies within the galena mass, which latter is deposited immediately in the granular dolomite. It will be seen that the crusts upon the stalactites present a varying order of succession, and that the stalactites have fallen from the roof at different stages of their growth.

* F. Pošepný, "Die Blei-und Galmei-Erzlagerstätten von Raibl." *Jahrb. d. k. k. geol. Reichsanst.*, xxiii., 1873, p. 372; also "Die sogenannten Röhrenerze von Raibl," *Verhandl. d. k. k. g. Reichsanst.*, 1873, p. 84.

That portion of the ore-deposit which surrounds the localities of these stalactites has an entirely normal structure, corresponding with that of other portions, and can only have been formed in the same way, namely, from ascending mineral solutions in the deep region. When, under such circumstances, a cavity contains stalactitic deposits instead of the ordinary wall-deposits, that particular part of the channel must have been filled with gas. The decomposition of the blende is due here, as in Wiesloch, to the subsequent action of the vadose circulation.

In the Mátyas Kiraly mine in Verespatak, from which I have already described the envelopment of gold-aggregates by various metallic carbonates and quartz, there has been found also a stalactitic form of analogous composition. This specimen is in my possession, but there are two others in the National Museum at Budapest which practically came from the same mine. One of the latter is shown in Figs. 29 and 30, and my own in Fig. 31, in twice the natural size. The latter showed, after being broken from the rock in which it occurred, a projecting thread of gold; and in polishing the surface several angular (and hence crystalline) gold-aggregates were found in the axis of the stalactite. The shaded portion indicates the pink manganese crusts, and the unshaded portion the colorless carbonates. The outermost crust, separated here and there from the others by a small druse, is quartz.

Wonderful occurrences of this kind must exist in the Vallé mines in Missouri; but we have only mere diagrams of them, which do not exhibit the true details and cannot be corrected with the aid of the accompanying text. The careful objective representation of a series of these tubular deposits would be a service to science. I shall recur to these relations, represented in Figs. 32 to 35, when I come to consider the Missouri deposits again.

The variety of the occurrences described above might be still further illustrated; but enough has been said to furnish from observation the elements for explaining the filling of all crustified deposits. When the elements actually found in such deposits are taken together with what we know of the conditions of underground circulation, no competent person can well believe in any other origin for these deposits than that of the circulation we have described. Whoever has followed the foregoing simple statement of the whole chain of phenomena will be led to distinguish sharply between the effects of the descending vadose and those of the ascending profound circulation, and to avoid the confusion of

the two which sometimes characterizes the discussion of the subject.

But there remains a serious difficulty in determining the genesis of non-crustified deposits. Here the indications, by which the structure and gradual growth of the deposit may be traced, are at first lacking. But they will certainly be found by patient search; and this knowledge must be furnished by engineers who have opportunity to study the phenomena on the spot where they occur, namely, in the mine.

The non-crustified deposits consist, however, of the same minerals as the crustified, and cannot well have a different origin; only we are not yet in a position to offer for them similar proofs of the manner of their formation. Certainly they also are the products of ascending mineral solutions; but they were not deposited in pre-existing spaces, and consequently they show no crustification. In describing various instances of this class, I shall have occasion to adduce some data bearing upon their genetic relations.

But even the crustified deposits need to be further illustrated by examples, especially because they seldom occur in nature in pure, unmixed types. We ought not to consider ore-deposits without reference to the medium which contains them; hence we must take into consideration the country-rock, and seek to represent the analogies of nature by grouping them graphically, as it were, with relation to two axes, representing respectively the genetic class and the country-rock. We may thus distinguish the following general groups:

Fillings of spaces of discission (fissures, etc.).

Fillings of spaces of dissolution in soluble rocks.

Metamorphic deposits in soluble rocks; in simple sediments; in crystallines and eruptives.

Hysteromorphous deposits (secondary deposits, due to surface agencies).

PART II.

EXAMPLES OF CLASSES OF DEPOSITS.

I have attempted to show above that in the two regions of subterraneous circulation the formation of ore-deposits must have taken place according to different, almost diametrically opposed principles: in the vadose region through descension and lateral secretion, and in the profound region by ascension, as the product of upward cur-

rents. I have pointed out that the deepest rocks reached by mining can scarcely be the original sources of the metallic solutions, and that these sources must lie at still greater depths.

That is to say, I advocate the views of the old school, and stand opposed to the assumptions of the new one, lately become popular, which does not need to go to inaccessible depths for the source of the metals, but professes to find it conveniently by simple chemical tests, without the necessity of leaving the laboratory and searching out the natural deposits. The new doctrine has thus far failed to take into consideration the two different underground regions; and we may expect that in proportion as it comes to do so, its conclusions will acquire quite another meaning.

I think it has been shown that the deposits of the deep region are precipitates from ascending springs. It remains to inquire, what has become of the substances which were not precipitated in such channels, but reached the surface in solution? Evidently these have been taken up, partly by the surface circulation, partly by the vadose underground currents; and, in the latter case, the deposition of such substances in the vadose region is possible. But I do not believe that we are as yet in a position to form a correct conception of the process of such a deposition; and therefore I leave this question open. Possibly, many impregnations, for which we can trace no direct connection with ascending springs, yet which are certainly not idiogenous (*i.e.*, of contemporaneous origin with the rock-matrix), may have originated in this way. Possibly, the sulphides which occur confined to the neighborhood of organic remains have been reduced from sulphates. But this must be confirmed in each case by a direct study of the facts, and not propounded as a safe generalization for all cases.

All these conclusions are based upon the undoubtedly correct hypothesis that the individual minerals of the deposits are precipitates from aqueous solutions. The important part played by the direct products of the barysphere—the eruptive rocks—is not ignored. But there has been a tendency of late to consider the proof of any solvents as superfluous, and apparently to assume that certain minerals were segregated directly from the eruptive magma. With respect to ferriferous oxides, this view has some foundation; but the notion, apparently held in some quarters, that sulphides also were thus segregated from the magma, surpasses my comprehension. It is true that pyrite is sometimes seen upon the lavas of active volcanoes; but this occurs, so far as I know, only when fuma-

roles and solfataras emit gases and vapors which decompose the rock, and therefore the agency of a solvent is not lacking. I am therefore obliged to conclude that aqueous solvents are the chief factor in the genesis of ore-deposits; and I shall be guided by this principle in the following illustrations of the leading genetic groups.

1. Ore-Deposits in Spaces of Discission.

The spaces produced in rocks by mechanical forces are predominantly fissures; but simple forms are sometimes rendered irregular by pre-existing conditions, such as those of stratification. Splitting upon a bedding-plane, coupled with a simultaneous longitudinal movement (such as gave rise to the ore-stock-works which the Norwegian miners call "lineal") may produce very complicated spaces, which must, however, be classed as spaces of discission.

Every fissure is the consequence of a tendency to dislocation transmitted into the rock. Hence the principal effect of the process is the production of the dislocation, not that of the fissure.* Where yielding stratified rocks are exposed to such a force, they first bend in its direction, and the fracture takes place when the limit of elasticity is passed. In such cases it is evident that the movement precedes the fracture. Fig. 70, from Rodna, and Fig. 69, from Raibl, are examples. In the latter, the gently southward-dipping contact between limestone and slate is bent and faulted by a N. and S. fissure. At Kisbánya, in Transylvania (Fig. 99), the strata of gneiss and chloritic slate, striking N. and S., are so bent by the E. and W. Nagynyerges vein as to give the appearance of an ore-bed.

Although the fissures produced by dislocating forces appear to be straight, they exhibit (as may be observed where veins have been traced for long distances) various changes of direction and more or less gradual curves. This hinders or checks the movement of one convex portion upon another, and promotes the creation of open spaces. The dislocating force, however, continually crowds the projecting surfaces together, and thus a space already partly filled with mineral deposit may be closed, or an open space may be filled with the detritus of friction. But the space finally left open facilitates communication with the deep region, from which it is filled.

* F. Pošepný, "Geol. Betracht. über die Gangspalten," *Jahrb. d. k. k. Bergakademien*, Vienna, 1874.

According to this conception, the vein-sheet must not be regarded (as is too often done) as a uniform plate of ore. On the contrary, it consists of several portions of very unequal value. The most valuable, doubtless, is the cavity-filling which forms the *bonanza* proper. In another portion the mineral solutions have been forced to penetrate the country-rock, and impregnate it with ore. A third portion remained altogether impenetrable to the solutions, and represents barren ground. These three kinds of ground may evidently show, at least in the same district, a certain regularity of relation; and of course it is most important to determine for a given district some law of distribution of the rich ore-bodies. In certain instances some knowledge of this distribution has been, in fact, successfully acquired for a given vein, before it had been exhausted by mining. In many other cases we cannot establish the law, even afterwards, because the most necessary records were not made during the exploitation. On the whole, we must confess that our knowledge of the laws of bonanzas is nothing to be proud of. In this respect the work of Professor Moissenet may be consulted.*

Obviously, in all such investigations, the question of the origin of the fissure must be separated from that of its filling. The former can be answered only upon the broad basis of a knowledge of the stratigraphic relations of the whole vicinity, and with reference chiefly to the physical properties of the rocks, while in the latter their chemical properties come to the front.

As a rule, however, the country-rock of an ore-vein is more or less altered, not only by decomposition, but also by subsequent solidification, thus rendering much more difficult the comparison with conditions existing far from the vein. This alteration of the country-rock is universally ascribed to the mineral solutions which deposited the ore; and it is not improbable that a close study of it might enable us to draw conclusions as to the nature of these solutions. Unfortunately, petrography is still confined mainly to fresh, typical rocks, and the study of the decomposed country-rock of ore-veins has not been cultivated so much as could be wished.

All veins which exhibit friction-phenomena, such as crushed country-rock, slickensides, and striations, are structurally fault-fissures. Such a vein may be conceived, therefore, as the boundary-surface of a mass which has undergone movement. The vein-phenomena of the Hartz especially support this conception.

* M. L. Moissenet, *Études sur les filons du Cornwall; Parties riches des filons; Structure de ces parties*, etc., Paris, 1874. Engl. tr. by J. H. Collins, London, 1877.

Some vein-fissures are confined to a given rock, and do not extend into the adjacent rock. These cannot be ascribed to structural dislocation, but must rather be considered as caused by changes of volume in the immediate formation. They are often called fissures of contraction. The most striking example which I have encountered is shown in Fig. 36, which is from the gold-district of Beresov, in the Ural mountains. Palæozoic slates are there traversed by a number of granite veins, 20 to 40 meters (66 to 131 feet) thick, and striking chiefly N. and S.; and each of these granite veins is again traversed by E. and W. gold-quartz veins, which at the borders of the granite either become barren or cease altogether. Near the Beresov is the Pysminsk district, in which the granite veins are replaced by diorite and serpentine; but strange to say, the gold-quartz veins occupy in these rocks the same position as in the peculiar Beresov granite, locally called beresite. Judging from Beresov alone, one might suspect the veins to have been filled from the granite; but the occurrence in Pysminsk suggests caution.

Finally, the veins of the well-known very deep mines of Przibram might be ascribed to the contraction of the eruptive dikes in which they occur (although they depart here and there into the stratified rocks); but we cannot dream of deriving their metallic filling from the dikes. The Commission, already mentioned, established to test the applicability of the lateral-secretion theory to Przibram conditions, found the material of the dikes to be the same in depth as in the upper zones. The largest amount of metallic contents attributed to the diorite dikes would account for a portion only of the thickness of ore in the veins. The greater part must certainly be regarded as of deep origin; and it is more convenient to treat the entire metallic contents of the veins as derived from greater depths.

Granting, then, that the vein-spaces at Beresov were formed by the contraction of the granite dikes, the vein-filling must be ascribed, like that of other deposits, to metallic solutions ascending from the deep region.

With regard to structure, the fillings of ore-veins very often exhibit distinct crustification, and sometimes even a symmetric succession of crusts from both walls to the central druse. But this phenomenon often retires into the background; crustification becomes indistinct or disappears, as is frequently the case in gold-quartz and other metamorphosed veins, in which its last traces appear in the crystal-tips of the central druse and the occasional indication of fibers perpendicular to the walls.

Sometimes one part of a vein shows distinctly a crustification which in other parts is discerned with difficulty, or is even wholly absent. Fig. 53 represents a specimen from the Drei Prinzen Spat vein in the eighth level of the Churprinz Friedrich August mine at Freiberg. It is interesting also by reason of the two dislocations which it exhibits. The oldest vein (*a*) of quartz, with irregularly disseminated galena and zinc-blende, is traversed and faulted by a second, very clearly crustified, vein, the filling of which consists of hundreds of very thin alternate crusts of (*b*) fluorite and quartz and (*c*) barite, symmetrically arranged on both sides, with a central druse (*d*) containing a gray earthy mass. A quartz seam (*e*) then faults both veins. The manager of the mine assured me that the specimen occurred in the vertical position in which I sketched it. (In order to be certain at all times on this important point, it is advisable, before removing a specimen from its natural position, to mark it in color with a vertical arrow, head downward.)

Very often the crustification of a vein-formed ore-deposit is only to be traced in the appearance of the whole, since each of many irregular veinlets may represent separate mineral crusts. Accurate pictures of such occurrences are highly instructive, since the complications are often so great that the most detailed description can convey no correct notion. Figs. 45 to 52, by reason of their small scale, do not give all the details contained in the originals from which they are taken. Figs. 45, 46, and 47 are from Weisenbach's famous book,* and represent Freiberg occurrences. The rest are from Austrian publications.† Figs. 48, 49, and 50 refer to Przibram, Figs. 51 and 52 to Joachimsthal. We have in Fig. 47 a specimen, so to speak, of the transition from a vein to a bedded deposit. But this is not the type called by the Germans bed-vein (Lagergang), which is strictly a fissure-vein, the fissure of which coincides with the plane of stratification instead of crossing it. Sometimes it is a joint or cleavage-plane (often confounded with the bedding) which the bed-vein occupies—a case which, I believe, I have found at Mitterberg in Salzburg and at the Rammelsberg near Goslar.

In this category belong also the instances of a squeezing of strata

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* *Abbildung merkw. Gangverhältn. aus d. sächs. Erzgebirge*, Leipzig, 1836.

† *Auf Befehl s. Exc. Julius Grafen Falkenhayn herausgegebene Bilder v. d. Lagerstät. d. Silber-u. Bleibergb. zu Przibram*, etc., Vienna, 1887. *Geol.-bergmänn. Karte mit Profilen von Joachimsthal, nebst Bildern von den Erzgängen*, etc., Vienna, 1891.

near the vein, so that hanging or foot-wall, or both, show for a certain distance a stratification parallel with the ore-deposit, and only beyond this zone does the normal stratification in a different plane appear. This case is best represented by Fig. 99, a sketch showing an E. and W. vein in a country of slate striking N. and S. The occurrences at Rodna (Fig. 70) and Raibl (Fig. 69) furnish also some illustrations, though here it is chiefly barren fissures which traverse and bend the stratification.

The text-books usually present only simple outline-sketches of such conditions; and accurate pictures are calculated to surprise those who have not been much in mines, by exhibiting the complications of the actual occurrences. (Of course, complete objective accuracy would require photographs of polished surfaces.) I will here refer only to one of the most complex pictures, shown in Fig. 47 and taken from Weissenbach's collection (*op. cit.*, Plate 22). The Gabe Gottes vein of the Bescheert Glück mine at Freiberg consists of separate masses of decomposed gneiss, bounded by barren fissures, and the stratification of which has been disarranged by their mutual pressure. The fissures have no filling, but the gneiss shows filling, nearly representing its stratification, *i.e.*, in planes almost perpendicular to the walls of the vein. According to my view, the vein being in this place split up into small fissures, a movement must have occurred, probably on the lowest of these fissures shown in the picture; but the result, instead of being an ordinary fault, was a pulling-apart of the hanging-wall strata, which created spaces perpendicular to the vein-plane, and approximately between the strata. These spaces were subsequently filled in the same way as was the simple main fissure itself in other parts of this vein. The case may furnish also an explanation for certain kinds of bed-veins.

The greater number of ore-veins, as of ore-deposits in general, occur in eruptive rocks—a circumstance which doubtless indicates that their metallic contents have been derived, directly or indirectly, through these or other media, from the barysphere. The most productive ore-veins are wholly in such rocks, but others occur in stratified rocks, traversed by eruptives. Comparatively few occur wholly in stratified rocks. In such cases large faults have unquestionably opened communication with the barysphere. To emphasize these relations, I will bring forward some illustrations from well-known ore-vein districts comprising such occurrences:

a. In stratified rocks, entirely unconnected with eruptives;

b. In the neighborhood of eruptive masses, and partially enclosed therein;

c. Wholly within large eruptive formations.

a. Ore-Veins in Stratified Rocks.

Genuine ore-veins entirely unconnected with eruptive rocks are not easily to be found—especially not in cases of important and well-studied districts. Clausthal, in the Hartz, still comes nearest to fulfilling these conditions. The Hartz range is a mass of folded palæozoic strata, which lifts itself, in lenticular form, above the North German plateau of mainly Mesozoic rocks. The strata comprising the Hartz generally strike at right-angles to the W. N. W. direction of the axis of the range, but most of the faults are approximately parallel to this axis, so that the terms "axial" and "cross" mean here the opposite of what they would mean in ranges the main axes of which coincide with the strike of the strata.

Clausthal.—The ore-veins of Clausthal are somewhat peculiar. There are zones of altered rocks, 20 to 80 meters (65 to 262 feet) wide and extending as far as about 15 km. (9 miles), in which the ore-bodies are somewhat irregularly distributed. These rock-zones are called vein-clay-slates (Gangthonschiefer), to distinguish them from the ordinary slates (Culmschiefer) of the district; and recent careful investigations have shown that their composition practically corresponds with that of the latter. They are therefore in fact country-rock, altered for the most part mechanically, and only to a slight extent chemically. They are foliated; but the foliation rather parallels the planes of movement, being somewhat steep, while the strata of the surrounding region have generally but a slight dip. These zones may therefore be best conceived as the result of the friction of the great masses which have here been rubbed together.

In recent times, chiefly by A. von Groddeck, it has been actually proved that these zones represent great faults, along which either the footwall mass was moved S. W. downward, or the hanging-wall was lifted N. E. The vertical movement, measured at certain points, would be about 400 meters (1312 feet); but it is probable that the movement of one mass upon the other did not follow the true dip, and that the horizontal component was much greater than the vertical. The faulted portions of a kersantite vein discovered by Groddeck show that each southern mass was moved further west, or each northern mass further east.

The network in these zones of dislocation is also peculiar. As indicated in Fig. 37, lenticular masses have been isolated, after undergoing severally a movement in the direction of the axis of the Hartz range; so that the whole zone of lenticular masses expresses the displacement which the solid crust has experienced. The structural significance of the zones is thus clearly disclosed, as a means of communication with a deep region from which the mineral solutions ascended, to deposit ores in the fissures of dislocation. As I have already remarked, an ore-vein is thus represented as the boundary of a displaced rock-mass, and so is brought into direct structural relation with the country-rock.

A glance at the geological map of the Hartz Mountains will show, however, that even this region is not free from eruptive rocks; for the stratified formations crossing the mountain axis are traversed by masses of granite, which have evidently played a part in the building-up of the range above the plateau. Moreover, according to the investigations of Dr. K. A. Lossen,* and others, contact-metamorphosis of the stratified rocks has proceeded from them. E. Kayser† fixes the elevation of the granite between the end of the Carboniferous and the beginning of the Permian, and since several of the faults extend into this rock, he thinks it cannot have been a factor in the fissure-formation. Lossen, on the other hand, is inclined to ascribe to the granite an active part in the formation of the ore-deposits, and (if I understand him correctly) to believe that these deposits were influenced by their position against the granite nucleus of the Hartz Mountains, which is said to lie steep on one side and more flat on the other, beneath the sedimentary strata.

Accurate geological surveys of the Hartz have noted a large number of fault-fissures, some of which connect the two great ore-deposits of Clausthal and Andreasberg. Those which are called *Ruscheln* resemble the dislocation-zones of Clausthal. They are fissures, up to 30 meters (100 feet) wide, approximately parallel with the mountain-axis, and filled with a clayey or fragmentary material, full of striations and slickensides and generally of dark color.

Andreasberg.—Roughly parallel with these *Ruscheln* run the silver-ore veins of Andreasberg, which carry ore only on one side

* "Geol. u. petrogr. Beiträge zur Kenntniss des Harzes," *Jahrb. der k. preuss. geol. Landesanstalt ü. Bergak für* 1881, p. 47.

† "Ueber d. Spaltensystem am S. W. Abfall des Brockenmassivs," etc., *Ibid.*, p. 452.

of the *Ruscheln*, and lose their ore when they approach the latter. It was formerly imagined that the two main *Ruscheln* enclosed a lenticular mass of the country, to which the silver-ores were confined; and H. Credner* still expresses this view. But Kayser (*op. cit.*, p. 443) observes that the mines have disclosed a convergence of the *Ruscheln* to the west only, and that a similar convergence to the east has been purely assumed from analogy, whereas the surface-indications are rather those of a wider separation in that direction. (See Fig. 38.)

We have here a case in which the ores occupy, not, as in Clausthal, a previously prepared zone of dislocation, but a network of veins. H. Credner has pointed out that the mineral solutions were unable to penetrate the walls of the dislocation-zones, and conceived in this connection that these walls enclosed a lenticular body of rock. But the main question concerns the origin of the more recent network of fissures. We must assume that when the dislocation-zones were formed, the mineral solutions had no opportunity to enter them, because (as was the case in many great faults, *e.g.*, those of Przibram) no spaces of discission were formed. Afterwards, however, a second system of fissures originated, adjusting itself to the conditions created by the first, and producing rock-fragments, the relatively slight movement of which did not fill the interstitial spaces with the detritus of friction.

But outside of the angle between the *Ruscheln*, there are also veins, which, considering their direction, may be continuations of the silver-veins inside, although, being differently filled, they are not so regarded.

It was formerly attempted to connect two eruptive rocks with the formation of these ore-veins; the granite which appears to the north, beyond the fault-fissures; and the diabase which touches them at many points to the south. The latter, however, is now considered to be a stratified layer in the series of the country. Both rocks have been passive in the formation and the filling of the fissures, and we must look again to the deep region as the source of the ores.

b. Ore-Veins in the Neighborhood of Eruptive Masses.

The Erzgebirge.—It would be impossible here to pass in review the innumerable veins of the *Erzgebirge* in Saxony and Bohemia. Such a review will soon be furnished by the publication of a work

* "Geogn. Beschreib. d. Bergwerksdistriktes von St. Andreasberg," *Zeitsch. d. deutsch. geol. Gesell.*, xvii., 1865, p. 221.

on this subject by the eminent Saxon mining geologist, H. Müller (who has received the honorary title of "Gangmüller," to distinguish him from the many other Müllers of Germany). In this region, veins in the greatest variety occur in gneiss, with here and there an eruptive dike; but the latter can scarcely be considered as more than indications of a former communication with the barysphere.

Besides different porphyries and diorites, there is an occasional dike of basalt. At Joachimsthal, in Bohemia, we can recognize pre- and post-basaltic ore-deposition. We find here, as in many other districts, two vein-systems at right angles; one striking N.–S., and accompanied with porphyry dikes; the other striking E.–W., and accompanied with dikes of basalt and (according to recent views) phonolite. The E.–W. fissures are occupied partly by basaltic dikes, partly by ore-veins which were deposited, some before and some after the basalt, a satisfactory proof that the fissures were formed at the period of basaltic eruption. How far the basalt took part in the ore-deposition, however, has not yet been shown.

In the basaltic and "basalt-wacke" dikes of this district, at the considerable depth of some 300 meters (984 feet) below the surface, petrified tree-trunks were found, a fact which furnishes an analogy to the reported discoveries in the Bassick mine in Colorado.

Przibram.—An entirely different picture is presented by Przibram in central Bohemia, where we encounter not only a great structural fault, but also eruptive dikes, which are followed by most of the ore-veins.

In central Bohemia the general strike is NE.–SW. for all rocks except the diorite dikes, which strike N.—S., thus varying 45° from the prevailing direction. Above the granite lies first a formation of pre-Cambrian slates; upon this follows unconformably the Cambrian system, consisting below of conglomerates and sandstones, and above of fossiliferous slates. Sections across the strike show repetitions of the pre-Cambrian and Cambrian strata due to great faults, which likewise strike NE.–SW. (Fig. 40).

The one main fault which has been exposed by mining to the depth of 1110 meters (3600 feet) is properly a so-called *Wechsel*, by which the older stratum (in the hanging-wall of the fault) has been slid over the later stratum (in the foot-wall). Several other faults, similar in character, though not explored on an equal scale, occur in the district; and it may be imagined that before this shoving together of the Palæozoic strata of central Bohemia they must have occupied a much larger area than at present.

This main fault, called the "*Lettenkluft*," is constituted by a zone of clay and crushed rock, from 2 to 10 meters (6.5 to 33 feet) wide. At Przibram itself, the sandstones which contain the ore are succeeded in the hanging-wall side by pre-Cambrian slates. A little further SW., at Bohutin, granite appears on the hanging-wall of the *Lettenkluft*—evidently, as the cross-section indicates, the granite foundation, here outcropping a second time, of the whole palæozoic series.

Numerous N.–S. dikes occur, and in the ore-bearing zone they are so close together that some cross-sections show them to constitute almost one-third of the total rock-mass. The ore-veins are mostly in these diorite dikes. Only occasionally do they enter the stratified rocks, returning soon to the dikes they have left, or to others of the group. In dip also they mainly follow the dikes, so that we may here assert with confidence that the already existing dikes determined the formation of the ore-bearing vein-fissures.

As already narrated in Part I., this district was made a test of Sandberger's lateral-secretion theory. Careful and repeated analysis showed the presence of metals in the rocks, but could not decide the question whether these metals were primitive ingredients or secondary impregnations. Since such metallic traces occur in both the eruptive and the sedimentary rocks, but cannot possibly be in both cases primitive, it is probable that they are in both cases secondary. There is then in this case, notwithstanding the connection of the ore-veins with the dikes, no proof that they were formed by the leaching of the country-rock. If the vein-material (as is very likely), was derived from eruptive rocks, these were situated much deeper than the eruptive rock disclosed down to 1110 meters (3600 feet) below the surface, or 564 meters (1850 feet) below sea-level.

The Cambrian sandstone basin of Przibram is unsymmetrical; one side dips gently northwest, the other (next to the fault) slightly southeast. In the latter part, which is also more highly metamorphosed, lies the bonanza or rich ore-ground, which therefore starts *from the intersection of the great structural fault with the zone of eruptive rocks*, in other words, from the point relatively nearest to the barysphere.

In the steeply-dipping sandstone series, certain strata are petrographically characteristic; and when these are traced to the intersecting dikes, it becomes clear that the latter (and hence the ore-veins also), are fissure-faults. Thus Fig. 39, a section through the Franz Joseph shaft, shows dislocations of the strata (adinole-beds) as great as about 200 meters (656 feet).

It should be added, that the dikes present different kinds of eruptive rock, and that they are generally decomposed in the neighborhood of the ore-veins—a result naturally to be attributed to the action of the mineral springs; also, that stratified rocks show, near the granites, a contact-metamorphosis which has converted them into hornstone. This phenomenon recalls the Hartz, especially the St. Andreasberg district.

c. *Ore-Veins Wholly Within Large Eruptive Formations.*

Hungary.—If we turn to Hungary, we find many veins wholly included in eruptive rocks. One of the best known districts is that of Schemnitz, which presents in geological conditions the nearest analogue of the Washoe district and the Comstock lode in Nevada.

In both cases, various eruptives, principally Tertiary, such as diorite, andesite, trachyte and rhyolite, ranging to basalt, are spread over a Mesozoic (mainly Triassic) foundation. The N. and S. extension of these masses and of the ore-veins they contain is alike in both districts. The number of veins at Schemnitz is very large, and they exhibit a very great variety of filling. In some of them, so-called "ore-columns," *i.e.*, specially rich ore-channels (chimneys or shoots), have been recognized. Those in the Grüner vein, according to M. V. Lipold,* are short horizontally, but much prolonged in the direction of their pitch, obliquely on the dip of the vein. In other ore-veins, *e.g.*, in the Spitaler master-lode, which is about 40 meters (131 feet) wide, and has been traced for 8 km. (5 m.); also in the Bieber and other veins, the ore-bodies are said to have covered large areas of the vein-sheet. The ore richest in gold is reported to be the so-called *Zinnopel*, a crust consisting of jasper, with pyrite, chalcopyrite and galena, which surrounds fragments of an earlier quartz crust.

In the trachyte range of Vihorlat Gutin, which runs NW. and SE., approximately parallel with the Hungarian boundary, there is a series of gold and silver mining districts, containing occasional large veins with numerous small ones. Among the former are those of Nagybánya and Felsöbánya, where several domes of trachyte or of andesite, breaking through the late Tertiary "*Congerien*" strata, are in turn traversed by large veins, which split up near their outcrops, so as to exhibit in vertical cross-section a fan-shaped arrangement.

* "Der Bergbau von Schemnitz in Ungarn," *Jahrb. d. k. k. geol. Reichsanst.*, 18 7, p. 403.

Further east is the Kapnik mining district, containing a series of separate veins; then comes Rota, similar in character; and finally (over the line in Transylvania), the district of Oláláposbánya, the veins of which are partly in the eruptive rock, partly in the old Tertiary strata which it traverses.

Throughout the range, silver-ores predominate, occasionally with a considerable gold-value. In the eastern portion, copper-ores appear.

The Dacian Gold-Field.—In southwestern Transylvania, in the Dacian gold-district, all the gold-mines are grouped in connection with four separate eruptive zones of recent origin. The main rock of the region is Cretaceous sandstone, with occasional exposures of Jurassic and Triassic strata, the latter of which include heavy outflows of melaphyr, and also masses of crystalline rocks. The recent eruptives, comprising porphyry, diorite, andesite, basalt, etc., occur in a triangle, the base of which is formed by the widest range, the Cietrasian, which strikes NW. and SE., and in which are the mines of Nagyag, Magura, Füzesd, Boitza and Ruda. In a second, approximately parallel range, are the mines of Faczebaja and Almás; in a third, those of Vulkoj and Verespatak and in a fourth, forming the apex of the triangle, those of Offenbánya.*

These mines, which are for the most part very ancient (pre-Roman), I shall treat fully in a monograph now in course of preparation. In the whole Dacian gold-district the predominant deposits are fissure-veins, sometimes represented by mere "knife-blade" seams, continuous for short distances only. In some places, as in the celebrated Verespatak district, other types of deposit are represented, the ores of which, however, also occur in spaces of discission, namely, in eruptive breccias, between the related fragments, in the form which I have elsewhere called typhonic masses; but these are ore-bearing only where they are in contact with the ore-veins. The same is true of the conglomerates into which these breccias sometimes pass, and in which the ore takes the place of the interstitial cement, as I have explained in a preceding chapter, and illustrated in Fig. 18. For further elucidation, I show in Fig. 41 a breccia, and in Fig. 42 a conglomerate. (It should be observed that the mutual relation of the fragments of a breccia can be recognized only when they have not suffered much movement after fracture). In both these speci-

* F. Pošepný, "Allgem. Bild d. Erzführung im Siebenb. Bergbau-Distrikte," *Jahrb. d. k. k. geol. Reichsanst.*, xviii., p. 297.

mens, the rock is quartz-porphyry with quartz-crystals of pea-size. In Fig. 41 the interior of the fragments is considerably decomposed, whereas the exterior shows a thin layer, either of undecomposed rock, or of material subsequently impregnated with silica from the open interstices, and thus made capable of resistance. Sometimes the porphyry is found to be traversed by a complex network of fissures, filled (except as to some wider spaces of intersection), with a clastic mass, like sandstone. The interstices of the conglomerate, Fig. 42 (except the spaces containing crusts of manganese spar and quartz) are filled with a clastic cement, mostly silicified into hornstone.

This sort of ore-filling is comparable in some degree with ore-deposits in soluble rocks, when the filling has passed from the space of discission proper into the rock, after room has been made for it in the latter by dissolution. In the cases before us such room was made by the partial washing away of the (probably clayey) cement of the breccias and conglomerates.

Verespatak.—The gold-district of Verespatak is situated at the north end of the second eruptive range. The two porphyry masses of Kirnik and Boi form a center, around which sandstone and porphyry-tufa lie almost horizontally, and in part unconformably, upon folded Cretaceous sandstones below. The whole district is surrounded by a zone of trachytes, andesites, and their lavas, which once (as may be inferred from the fragments remaining on the porphyry and tufa) overspread the entire district, and have been removed by erosion, laying bare the two older eruptive masses of the porphyry.

A funnel-shaped depression seems to have been formed in the folded Cretaceous strata, from the middle of which ascended the porphyry-outflows, furnishing also the material for the porphyry-tufa, which fills this funnel-shaped basin.

The principal gold-bearing rock is the porphyry, yet the tufas and the Cretaceous rocks near the porphyry-outflow carry gold; whereas, no gold or ore of any kind occurs in the trachytic and andesitic lavas which once covered the region.

Vulkoj.—At Vulkoj, however, at the southern end of the second eruptive range, almost the opposite is the case. Here the older and deeper quartzose rock carries little ore, while gold abounds in the overlying andesites. Several mines of the Dacian gold-district have encountered in depth the stratified rocks through which the eruptives came, and the result has generally been disastrous to the miner, the ore-veins having either ceased entirely or become pinched to barren fissures. In the first case it would appear that the vein-fissures had

been formed by the contraction of the eruptive material. But, in general, it should be said that these phenomena are by no means clearly and reliably reported. The prejudices of the miners play too large a part in their reports. This much is certain, that any fissure, in passing from one rock to another, is likely to exhibit a certain irregularity in both direction and filling, and that a change of this kind should not be allowed to discourage at once all further exploration.

In some cases there has been found, below an eruptive rock containing ore-veins, a decomposed breccia of the same, which was quite barren. The great porphyry mass of Kirnik, at Verespatak, has been pierced through and through with ancient and modern workings, like the pores in a sponge. In recent years deep adits have been driven into it to reach fresh ground, but with unsatisfactory results.* A short time ago the deepest of these adits encountered in the nucleus of the Kirnik mass not the ore-bearing porphyry, but decomposed clastic rock and porphyry-breccia, which may be supposed to be the filling of the crater-opening. The Vulkoj mass, which has been almost cut into two halves by very ancient open-workings along its crest, contained a series of N.–S. veins, the richest of which (the Jeruga) was cut in depth by adits from both sides. On the south side appears a slaty Cretaceous rock, underlying the porphyry, and extending (see Fig. 43) upon the Jeruga plane, with two offsets, to the deepest adit on the north side, where it strikes the decomposed breccias, in which the very rich ores mined above can no longer be found to continue.

As to the continuation of the veins in the slaty rock, the following facts are pertinent. West of the Vulkoj mass, in the sandstones and slates, there is another gold-field, that of Botesiu, the veins of which are analogous, both in strike and in ore-filling, to those of Vulkoj. Botesiu shows no eruptive rocks; nevertheless, a study of the whole region shows that the formation of its vein-fissures must have been connected with them, and it is even not impossible that they may once have extended as far as this, and may have been removed by subsequent erosion. It follows that we must assume the Vulkoj veins to extend below the andesite into the slate, though this has been doubted by some. Fig. 44 shows the situation in an E.–W. section.

In the region of Boitza the eruptive zone (predominantly of quartzose dacites or porphyries) crosses an exposure of Mesozoic limestones and melaphyrs, and the veins pass directly from the porphyry into the underlying melaphyr.

At Nagyag, Magura, and Füzesd, in following the gold-veins in depth, masses of Tertiary sandstones and conglomerates are formed, broken through and enveloped by the eruptive rocks.

At four places in the Dacian gold-district, namely, Offenbánya, Faczebaja, Fericiel, and Nagyag, telluric ores occur. In the neighborhood of Zalathna there is cinnabar, and at several points near Kōrōsbánya there are copper-ores carrying a little gold. Gold is, however, mainly connected, as has been observed, with the four ranges of Tertiary eruptives, and appears chiefly in these rocks, though also in the stratified rocks which they traverse.

The occurrence of gold in this case is thus somehow related to the eruptions; but since I have never found it as a primitive or idiogenous constituent of these rocks, I do not believe that it was derived originally from them. There is, therefore, nothing left but to consider the eruptions as the agents of a communication with the deep region, from which at these points the mineral springs ascended. The Dacian gold-district will furnish, upon further exploration, important contributions to the inquiry into the original source of the gold. For instance, if the auriferous character of the veins of Vulkoj should be found to continue in the shaly sandstones underlying the andesite, my view would be confirmed.

The Comstock Lode.—The most thoroughly studied American vein-phenomena bearing on this question are doubtless those of the Comstock lode. It is not necessary to enter here upon a detailed description. I content myself with a reference to the three large treatises upon the district,* of which Becker especially discusses the genetic question. To appreciate this question, however, some simple illustrations are required; and these have been compressed into Figs. 58 to 63.

As already observed, the general geological conditions of the Comstock lode show a strong analogy to those of the Schemnitz district. Only occasional bodies of sedimentary rocks are found, while the principal mass of the whole elevated region consists of a great variety of eruptive rocks, principally of the more recent periods. The altitudes of the more important points above sea-level are about as follows:

* Clarence King, *U. S. Geol. Explor. of the 40th Parallel*, iii., *Mining Industry*, Washington, 1870.

J. A. Church, *The Comstock Lode: Its Formation and History*, New York, 1879.

G. F. Becker, "Geology of the Comstock Lode," etc.—*U. S. Geol. Survey, Monograph*, iii., Washington, 1882.

	Meters.	Feet.
Mount Davidson (the highest point of the region),	2420	7941
Outcrop at the Gould and Curry mine (the datum-line for measurements of depth),	1950	6400
The Sutro Tunnel, at different points, 1840 to 1865 feet below datum-line,	1390 1382	4560 4535
The deepest point in the Belcher and Crown Point shaft, 3414 feet below datum,	910	2986

These figures alone indicate the immense extent of the eruptive material.

The stratified rocks occur in a considerable continuous body at Gold Hill, in the southern part of the district, while in the northern part only a small body enclosed in eruptive rocks is found in the Sierra Nevada shaft.

The several eruptive rocks have been differently defined at different times, according to the changes in petrography and in the methods of investigation pursued. Becker distinguishes: 1. Basalt (B). 2. Later hornblende-andesite (LHA). 3. Augite-andesite (AA). 4. Earlier hornblende-andesite (EHA). 5. Later diabase or black dike (LDb). 6. Earlier diabase (EDb). 7. Quartz-porphyry (QP). 8. Metamorphosed diorite (MDr). 9. Porphyritic diorite (PDr). 10. Granular diorite (GDr). 11. Metamorphic rocks (M). 12. Granite (G). This classification is based upon careful microscopic examination.*

The two principal veins (the Comstock and the Occidental) strike N.–S., and the Comstock has been traced 5 or 7 km. (3 or 4 m.), according as its branches are omitted or included in the measurement. The position and the branching of the veins are shown in the sketch-map, Fig. 58, in which the two most important eruptive rocks, the diorite and the diabase, are emphasized by shading, the others being indicated by letters, as in the above list. The diorite forms the foot-wall from Gold Hill to Virginia City. South of Gold Hill metamorphic slates form the foot-wall, and even extend across in part to the hanging-wall side, as does the diorite to the north of Virginia City. Moreover, in one place a dike of diabase—the so-called "black dike,"—occurs immediately on the foot-wall.

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* Messrs. Arnold Hague and J. P. Iddings (*Bull.* 17, *U. S. Geol. S.*, 1885, "On the Development of Crystallization in the Igneous Rocks of Washoe," etc.), have stated as their conclusion that GDr, EDb and AA are identical; PDr is EHA; MDr is LHA; and LDb is B; apparent differences being due to conditions of cooling. In *Bull.* No. 6, *Cal. Acad. of Sc.*, 1886, Mr. Becker, after a reinvestigation of the locality, denies this conclusion *in toto*, so far as the Comstock rocks are concerned.

The hanging-wall is principally diabase, at least in depth. In the upper region it is sometimes covered with other eruptives, most frequently with hornblende-andesite.

On the whole (with variations at some places), the Comstock presents wide, gently-dipping masses, predominantly of crushed and decomposed country-rock, and enclosing large flat "horses" of the same. The filling is, as a rule, saccharoidal granular quartz (sometimes more compact), in which the ores are very finely disseminated. At some points they have occurred concentrated, forming the bonanzas to which the colossal gold- and silver-production of the district is due. The ores are silver-ores (stephanite, polybasite, argentite), with sometimes galena and zinc-blende. The bullion produced from them contains about half its value, or 6 to 7 per cent. of its weight, in gold.

Some of these bonanzas were in the upper region and came to the surface. Others (like the richest one of all, in the Consolidated Virginia and California mine) were found in the deep region; and it is asserted that they were limited on all sides, without connection with other ore-bodies. This would make them unlike our ore-channels or chimneys, which usually do have interconnection. But I cannot conceive of their formation in any other way than upon the hypothesis that in such places more open spaces existed, through which larger quantities of dilute metallic solutions passed and made deposits.

The distribution of the bonanza-areas upon the vein-area is quite irregular; and it has not been possible hitherto to trace any connection between the bonanzas and the petrographic or structural conditions in their vicinity. In form they are equally without any law, as far as has yet been observed. The bonanzas of the Con. Va. and Cal. consisted of a main body and three lenticular masses higher up, which, taken together, have a flat pitch to the north. The bonanza between Belcher and Yellow Jacket, on the other hand, followed the true dip of the vein; while the bonanza in Justice—a mine on the NW.–SE. branch, which dips NE. much less steeply than the main lode—shows again a north pitch.

This NW.–SE. branch of the Comstock shows a filling different in some respects from that of the main lode, and may be considered as a cross-vein, running into the Comstock, or into the black dike which accompanies its footwall. (Becker's atlas, ix.)

In the Justice mine, namely, the filling is mostly calcite, with little quartz, instead of quartz with very subordinate calcite, as in the main lode. According to Becker (*op. c.*, p. 219) the calcitic filling

is characteristic of the whole SE. branch. According to Church, (*op. cit.*, p. 173) compact crusts of calcite alternate in the Justice mine with thin quartz crusts. This is the only clear report of crustification any where on the Comstock. (I believe, however, that I was able to observe upon a rich specimen from the Con. Va. bonanza, after polishing, a parallel structure in the mineral aggregate. I received this specimen in 1876 from Mr. Fair, one of the "bonanza kings," as a sort of compensation for the refusal to permit me to enter the then rich mine!)

A comparison of the many cross-sections of the Comstock published by King, Church and Becker, and representing, of course, various stages of knowledge of the vein, shows that no normal or average section can be given, because the condition at different points on the strike are so different, and at some places, *e. g.* the junctions of the branches, developments have not given satisfactorily complete exposures. The sections, Figs. 59 to 63, are given (on a scale too small to show much) merely to illustrate the distribution of the country-rocks. They are reduced from Becker's monograph. In the three northerly sections the footwall is granular diorite; in the two southern (Yellow Jacket and Belcher), and along the SE. branch, it is metamorphic slate. In the southern portion, the so-called black dike (according to Becker, later diabase) appears on the foot-wall, and follows the vein beyond the point where the SE. branch leaves it. The hanging-wall is diabase, except at the northern end, where diorite becomes the hanging-wall as well as the footwall. In the upper region, however, earlier diabase is covered by other eruptives. Diabase is the hanging-wall of the SE. branch also; but in the footwall of that branch, besides the metamorphous slates, granular diorite and quartz-porphyry appear.

So far as the sources of the eruptive rocks can be inferred, they were all (except that of the diorite) on the hanging-wall side of the vein, as were also the mineral springs which subsequently decomposed these rocks. But the ascending thermal waters encountered in these mines were within the vein itself; whence it may be concluded that the ore-bearing solutions came by that road from the deep region, and not, according to the lateral-secretion theory, from the side. In other words, the Comstock ores were not washed from those rocks which have been mined between 1950 and 910 meters (6400 and 2986 feet) above sea-level, but from material lying much deeper.

The investigations of G. F. Becker were made at a time when

importance was still attached to Sandberger's theory, and the correctness of his method of inquiry was assumed. The matter takes a different aspect when we (quite justifiably) doubt whether the minute metallic admixtures detected by wet or dry analysis were originally in the rock, and acknowledge that they may possibly have entered it afterwards. This is evidently the case with the precious metals in the pyrite of the ore-bearing rock. That this pyrite is a secondary impregnation can be proved with the microscope, and is admitted by Becker also. In my opinion, any eruptive rock may give rise by metamorphosis to the type which we call in Hungary, greenstone, greenstone-trachyte, etc., and which F. von Richthofen named propylite, because of its frequent occurrence as the country-rock of ore-deposits. Whether the precious metals can be detected in this rock depends wholly upon its impregnation, or that of one of its constituent minerals, with pyrite. But it does not follow that this was the primitive condition. From this standpoint are to be regarded the metallic values reported by Becker, and here reduced, for the sake of better understanding, from cents per ton to grammes per 1000 kilograms. A pyrite washed from decomposed diabase, near the face of the north branch of the Sutro tunnel, contained 3 cents silver and 8 cents gold, *i.e.*, 0.72 grm. silver and 0.12 grm. gold, per metric ton. The pyrite from the slates in the Belcher mine carried even 18 c. (4.32 grm.) silver and 20 c. (0.30 grm.) gold. Fresh diabase is said to have contained 4 to 5 c. (0.6 to 0.7 grm.) gold; the diorite of Bullion ravine, only a trace; while the andesite yielded about as much as the diabase. Augite separated by Thoulet's method from the diabase was found to be eight times as rich as a corresponding quantity of the feldspar.

Comparative investigations are reported to have shown that the decomposed diabase contains only half as much silver as the fresh—a circumstance which was interpreted in favor of the lateral-secretion theory, on the assumption that the decomposed diabase had given up half its silver to the vein-filling.

Since the diorite in the upper portion of Bullion ravine shows only traces of silver, but at the mouth of the ravine, near the vein, contains a considerable amount, Becker considers this indicative rather of an impregnation of the rock proceeding from the vein.

Moreover, the andesites and quartz-porphyries also contain small amounts of silver; while the strongly calcareous metamorphic diorite carries 8 c. (1.92 grms.) per ton, which might be connected with the vein-filling in the Justice mine. Finally, the basalt con-

tains nearly as much silver as the older diabase; but the basalt cannot be cited as a source, because it comprises the freshest rock in the district, and shows no trace of decomposition in its olivine (Becker, *op. c.*, pp. 223–225). These facts would be favorable to the notion of lateral secretion, if only it could be proved at the same time that the metalliferous character was primitive. But our knowledge does not go so far as that; and the Comstock, like the deep mines of Przibram, ceases, therefore, to be a proof of the lateral-secretion theory.

The Comstock differs in many respects from typical ore-veins. It is properly a quartz-vein, in which, at various points, important ore-concentrations have been formed, not showing (except in the Justice mine) any clear crustification, though this may have been present at some time, and may have been obliterated by metamorphosis of the vein-mass, *e.g.*, through the replacement of calcite by quartz. It is also, in the main, a contact-vein, between a diorite foot- and a diabase hanging-wall, with steep spurs running upward into the diabase and traversing also still more recent eruptives.* Some of these peculiarities are represented in other districts.

2. Ore-Deposits in Soluble Rocks.

In this group we shall find two genetic types represented: the fillings of spaces of dissolution, and the metasomatic deposits, the origin of which will be particularly considered, together with some related metamorphic deposits in soluble rocks, which have not yet been sufficiently studied to be classed apart.

The expression "soluble rock" is to be understood in its ordinary sense of solubility in the waters commonly represented on the earth's surface. Acid and caustic waters will attack, more or less, nearly all rocks, though not so as to dissolve them completely, as we see limestone dissolved. I include especially among the soluble rocks, rock-salt, gypsum, limestone, and dolomite. Of the following instances I shall describe most fully those which I have personally studied, giving only the essential outlines of other related occurrences.

Rodna.—The ore-deposit of Rodna, in NE. Transylvania, is interesting to me (apart from analogies which it offers with Leadville, Colo.), as the first in which I had the opportunity to study the origin of an ore-deposit by replacement.

It is situated on the line of two andesite ranges, having a com-

* This is denied by Hague and Iddings, *op. cit.* p. 41.—See foot-note on page 279.

mon strike,—the Hungarian Vihorlat Gutine, stretching NW., and the Transylvanian Hargitta range, running SE.,—and at the point where this line cuts through the mass of the Rodna Alps. The predominant rock is mica-slate, with numerous intercalations of limestone, and is traversed by many dikes and masses of andesite. Ore-deposits have been found at many points in the district. The most important, situated in the Benyes mountain, was carefully studied by me in 1862, after the ore-bodies in the mine had been worked out. J. Grimm had examined the mine in 1834, and had considered the deposits to be primitive beds at the contact between limestone and mica slate, and to have occupied that position before the andesite eruption, by which they had been much shattered.

The ores (pyrites, black zinc-blende, and argentiferous galena, slightly auriferous, with quartz and calcite) often occurred, it is true, on the gently-dipping contact-planes; but in certain E. and W. lines they stood steeply, much like veins. In these places the flat deposit, and with it the stratification, had suddenly turned upward; and it was clear to me that the occurrence represented a peculiar form of fault, namely, a bending of the strata, followed by fracture in the direction of the dislocating force, when the limit of cohesion had been passed. Here and there, in these steep places, the stopes had been carried beyond the contact, and the resulting appearance was as if the steep deposit had been the primary one, and had supplied the ore to the contact. Occasionally eruptive breccias were observed along the steep deposits. At lower levels, in the downward continuation of the fissure of the steep deposit, eruptive rocks and thin breccias occurred; and these became predominant in the lowest part of the mine.

The structure of the ore-beds was mainly massive, and not crustified. In some places, however, druses had been developed, which showed the same paragenetic succession as the mass of the bed, and which contained pseudomorphs of pyrite and galena after calcite. The thickness of the ore-bed was extremely variable, the greater part of the contact-area being scarcely worth working, while at single points colossal masses of ore were found. These circumstances led me to consider the deposits, not as contemporaneous in origin with the rock, but as subsequently formed by the circulation of mineral waters along the contact-planes. In other respects I adopted at that time the explanation of J. Grimm.*

* Some results of my studies at Rodna will be found in the *Verhandlungen d. k. k. g. Reichsanst.*, 1865, pp. 71, 163, 183, and 1870, p. 19.

Mining was then active chiefly on the north slope of the Benyes divide; and the sedimentary rocks were cut off towards the south by andesite. I pointed out that on the south slope, beyond the andesite, there were various ancient mines, and recommended that they be explored in depth, by means of an adit. This led to the discovery of several deposits, which gave new life to the industry. After cutting through the andesite, the explorers found steep deposits at the contact of andesite and limestone, and, in the limestone, near its contact with the mica-slate, a flat deposit, which, being above the ground-water level, had been transformed into carbonate of lead.

The somewhat complicated conditions are shown in Fig. 70, as far as this can be done in a single section. The deposit at the contact of andesite and limestone indicates at once a genetic connection with the eruptive rock, and renders it probable that the ore-beds also are due to the after-effects of the eruption. Even on the north slope there were some reasons for this conclusion. For instance, at the ore-bodies locally called *Thonstrassen*, ores occurred in the midst of eruptive breccia, which could not be taken for fragments of the original bed. Baron Constantine von Beust* found traces of "ring-ores," indicating a formation in open cavities.

In seeking an explanation of all the facts, I was led to give up the view of J. Grimm,† which he, however, still maintained, citing Offenbánya as another instance in which a pre-existing deposit on the contact between limestone and mica-slate, had been shattered by an andesite-eruption. But in that instance, also, I had the opportunity to satisfy myself that the then accessible mine-workings showed no fragments of an earlier ore-deposit, but only ore-formations under the influence of the andesite.

Grimm had had in mind the deposits of Rodna and Offenbánya when he established, under the first division in his systematic classification,‡ the second sub-division, "Occurrences of Ores as Fragments of Earlier Deposits, in Breccias," etc.

Offenbánya.—Offenbánya, in the Transylvania gold district, has various deposits analogous to those of Rodna, and also veins, with

* "Bemerkungen über d. Erzvorkommen von Rodna," *Verh. d. k. k. geol. Reichsanst.*, 1869, p. 367.

† J. Grimm, "Zur Kenntniss des Erzvorkommens bei Rodna," *Verh. d. k. k. geol. Reichsanst.*, 1869, p. 367; and F. Pošepný, "Die Natur der Erzlagerstätte von Rodna," *ibid.*, 1870, p. 19.

‡ *Die Lagerstätten der nutzbaren Mineralien*, Prague, 1869, p. 32.

telluride ores. We are here interested in its mass-deposits, at the contact of limestone and andesite, one of which is illustrated in Fig. 71.

Beneath the limestone widely extending through the district, mining has disclosed a mica-slate (the so-called underground slate); and at the contact of the two a flat, pyritous deposit. The whole stratified series is traversed by andesite; but near its contact with the limestone a steep, rich mass-deposit extends from the surface down to the mica-slate. This deposit is highly crustified, and was evidently formed in a pre-existing space.

The flat deposit shows no crustification, and may have been formed by metasomatic replacement of the lime at the contact between the impermeable and the soluble rock. The analogy with the conditions on the south slope of the Benyes mine, at Rodna, is evident, though I do not know whether at Rodna the flat deposit has been followed as yet to its junction with the steep one. *

Rézbánya.—Rézbánya in S. E. Hungary represents different conditions. Here, in an indistinctly stratified Mesozoic limestone, occur long spaces filled with ore, descending steeply and irregularly in shape like that of the cavity produced by pouring a stream of warm water upon a snow-bank. This extreme case is of great theoretical interest, although such ore-bodies having but one considerable dimension, and that in the most unfavorable direction for mining, mainly downward, are not attractive from a commercial standpoint. I visited Rézbánya first in 1868, and published some observations concerning it, which may have contributed to induce the Hungarian government to take up the subject later, and intrust to me a more thorough investigation. I will here mention only some things, interesting from the genetic standpoint, and refer for details to my published monograph upon the subject.†

In the Rézbánya region, lying above clay slates and Permian and Liassic sandstones, appear numerous isolated bodies of limestone, indicated by their fossils to be of various ages, from the Lias to the Neocomian, seldom distinctly stratified, and, when they are traversed by eruptive rocks, often showing a crystalline structure.

* At the time of the visit of G. vom Rath, in 1878 (described by him in the *Zeitschr. d. d. geol. Gesellsch.*, xxx., 1878, p. 556), this ore-body, 28 meters (92 feet) thick, had been developed for a height of 85 meters (280 feet) and a length of 120 meters (394 feet) without reaching its termination.

† *Geologisch-montanistische Studie der Erzlagerstätten von Rézbánya*, Budapest, 1874.

The ore-filling is mostly confined to the neighborhood of the eruptives, and sometimes to the contact, where garnet-rock occurs as a well-known product of local metamorphosis. Since my examination, there may have been, in this region, many interesting and scientifically important developments, which are unfortunately unknown to me. On the basis of my old notes only, I shall confine myself to the description of a single district, cut off from commercial communication, that of Valle Sacca. The name is that of the valley, which heads in a high mountain range of Permian and Liassic sandstones, and after a short course ends in a wild limestone cañon, leading into the Galbina valley. The sides of Valle Sacca consist chiefly of limestone, which is traversed by a number of eruptive dikes and one larger mass of a syenitic character. Fig. 64 gives a somewhat generalized section of the NW. slope of the valley and district on the line of the so-called fourth adit. At the adit-mouth is cut the syenite mass, which extends also to the opposite slope; and the adjoining portion of the limestone has been metamorphosed to a crystalline mass, while the limestone further SW. is for the most part still compact. On the west side, the limestone adjoins sandstone along a N.–S. line, which doubtless represents a large fault. Approximately parallel to it run the greenstone dikes, which, though they seem to be mutually parallel, in reality intersect one another at very acute angles, thus constituting a highly elongated net-work. The dikes are not alike. Most of them may be considered aphanitic or dioritic; one, however, is quartz-porphyry, with dihexahedra of quartz, of pea-size.

The principal deposit is the so-called Reichenstein stock, which had been worked, during the period prior to my visit, to a depth of about 400 meters (1300 feet), from its outcrop, 340 meters above the deepest adit, to a level 60 meters below the adit. Fig. 65 shows the form of the ore-channel on the strike. The horizontal section of the body was most frequently circular or elliptical. In some places one dimension strongly predominated, so as to give the appearance of a fissure-filling. At the outcrop, according to the old maps, there was but one channel. Below, this divided into neighboring and mutually connected branches. Several of these might continue parallel and independent for considerable distances. The total sectional area of these channels averaged perhaps 20 to 30 square meters (215 to 322 square feet); but at some levels the deposit was only present in traces, whereas at others it had many times its average section. Fig. 66 shows, by the difference between the plumb-line and the

arrow, the angle between the true dip and the pitch of the ore-body, oblique to it.

The ores were doubtless sulphides originally, but were afterwards oxidized in places. Rich silver-ores predominated, especially argentite, pieces of which weighing several pounds appear to have been no rarity. Besides this mineral there were hessite (telluride of silver), tetrahedrite, redruthite, galena, bismuthinite, and various pyrites. Taking these together with the oxidized ores, the deposit represented a whole mineral cabinet. The maximum silver-value was reported as 12 to 20 kilos per 1000 (1.2 to 2 per cent.), the gold being 3 grammes to each kilo of silver. The percentage of lead was about twenty times, and that of copper about ten times, as great as of silver. The metric ton (2206 pounds) would yield, at this rate, 24 to 40 per cent. of lead, 12 to 20 per cent. of copper, 12 to 20 kilos (386 to 643 ounces troy) of silver, and 36 to 60 grammes (1.15 to 1.83 ounces troy) of gold. The deposit was therefore a bonanza in the American sense. In fact, it yielded from $100 to $150 per ton.

Although I could not see this deposit in process of extraction, I was able to conclude positively, from specimens of the ore and from the analogy of similar deposits in the district, that it had been formed by the precipitation of successive crusts.

As regarded the origin of the cavity, I was at first influenced in my views by the numerous caves of the region. The mines repeatedly reached caves, into which the mine-water could be discharged without filling them, there being some subterranean outlet. But these caves, as I have explained in Part I., were formed by descending liquids of the vadose circulation; and to assume a similar origin for the cavities filled by the ore-bodies would be to assume that the latter cavities were formed in a manner directly opposite to that in which they were filled—which is highly improbable.

It was not until later, when I had become acquainted with the observations of J. Nöggerath (*ante*, p. 241) on the thermal springs of Burtscheid, that I recognized that ascending mineral springs are able to cut their own way to the surface, forming the channels which they ultimately fill with ore. The most difficult feature of all, namely, the nearly cylindrical form of the ore-bodies of Valle Sacca, was thus satisfactorily explained.

The channel of the Reichenstein body runs vertically for 400 meters (1312 feet) in limestone between greenstone dikes; or, in other words, in a zone of lime between two zones of impermeable

rock. The dikes therefore control its direction. It follows downward nearly at the angle of their steepest dip, but with a pitch southward, giving it a "false dip."

The sections of the various workings show that the ore-body apparently ended at one side of the dike and recommenced at the other side, as if it had passed through. In that case, porous places in the dike-mass, at the intersection, will have determined the track of the channel. It is significant that the Reichenstein ore-channel passes in depth through the dikes to the SW., towards what is probably a great fault-fissure, and not in the direction of the present drainage. Nor could the former deep drainage from this channel have been to the NE., along the contact between the limestone and the underlying Liassic sandstone (which, in fact, appears at a lower level, where the Valle Sacca joins the Galbina valley), for the reason that all the barriers of the greenstone dikes, unquestionably extending from the limestone into the sandstone, would have opposed that flow. The stratigraphical conditions thus exclude the possibility that this channel was formed by vadose circulation, and render more probable the view that it owes its origin to the ascending waters of the deep circulation, which certainly effected the filling of it.

Raibl.—Raibl, in Carinthia, is the best representative of a group of deposits which were at a recent period taken to be genuine beds even by M. V. Lipold,* then the best authority on the mines of the Alps in general. Here and there, as, for instance, by A. Morlot,† observations were made which threw some doubt on this conception; but since they did not fit into the prevailing system, they remained disregarded. It was my fortune to establish the truth of the situation. Prof. von Groddeck kindly characterized my investigation of it as "opening a new path," and adopted the filling of spaces of dissolution as a class in his system (*op. cit.*, pp. 10, 236, etc.).

Such deposits occur in Carinthia, in an E.–W. limestone alpine range, of which Raibl is the western end; and also somewhat further north, in the zone of Bleiberg near Villach, chiefly in a limestone, early denominated for this reason the ore-bearing limestone, and more recently determined as Triassic.

The ores occurred mostly in the vicinity of certain intercalated slates, which seemed always to occupy the same "Raibl horizon," and thus led to the conclusion that the ore-deposits (naturally believed to be of contemporaneous origin) likewise occupied a fixed

* *Jahrb. d. k. k. g. Reichsanst.*, 1862, *Verh.*, p. 292.

† *Ibid.*, 1850, i., p. 266.

horizon. But it soon appeared that the slate at Bleiberg belonged to a somewhat different horizon in the Trias; and I ventured to assert that the impermeability of the slates, as compared with the solubility of the limestone, had had something to do with the ore-deposition, which was a secondary formation in the rocks.

There are found at Raibl, some distance below the slates, in the limestone which conformably underlies them, what seem indeed at first glance to be beds of ore. They consist chiefly of a coarsely crystalline galena, with pyrites, and a zinc-blende (wurtzite) in very thin crusts, hence called *Schalenblende*. A closer study, however, of the extremely distinct crustification reveals that it does not represent the stratification, which, on the contrary, it crosses at all angles, being in fact the filling of irregular spaces, traversing the limestone in every direction.

Further light is furnished by the seams which here occur. As is generally the case in limestone, these are rarely wide fissures, but usually mere partings between two polished walls in close contact. Slickensides, etc., identify them at once as results of friction, caused by the forcible rubbing together of walls perhaps originally irregular. The plane of contact with the slates offers a means of determining the extent of the movement along some of these insignificant-looking seams; and it appears that dislocations as great as 40 to 60 meters (131 to 196 feet) have thus taken place. Since the slates possess some flexibility, they were sharply bent in the immediate neighborhood of the fault, a feature which, on account of its theoretical importance, I have illustrated in Fig. 69.

In the seams themselves (locally called *Blätter* or "leaves") there can be, of course, no deposit of ore; but such deposition occurs outside of the fissure, when soluble rocks like this limestone are traversed. Geode-spaces were thus leached out, and are found filled with distinct mineral crusts, as is shown in Fig. 72, representing the face of a level on the so-called *Johanniblatt*.

It cannot be doubted that the ore supply came from the seams; and when we find such seams also in large and rich deposits of similar character, like those on the north slope of the Königsberg at Raibl, we must concede to them a similar significance as regards the ore-deposition.

To the more important of these seams, J. Waldauf von Waldenstein* and Dr. W. Fuchs† had already called attention. These are

* *Die besonderen Lagerstätten d. nutzb. Mineralien*, Vienna, 1824, Plate III., Fig. 4.

† *Beiträge zur Lehre von den Erzlagerstätten*, Vienna, 1846, Plate I., p. 23.

the Morgen, Abend, Johann and Joseph. The first three meet at an angle of about 30°, and form the boundaries of ore-bodies, extending downwards along the seams with a horizontal length of 40 to 80 meters (131 to 262 feet) and a total thickness (including portions too poor to work) of 10 to 50 meters (33 to 164 feet). Many of the mine-managers believed that there was here a continuous ore-bed which had been faulted into separate bodies by the seams, and numerous exploring levels were undertaken to develop this assumed bed, but all in vain. Nothing was found, except a few more or less independent ore-shoots on one or both sides of the seams, similar to those which have been encountered in recent years at Leadville.

The foregoing observations will facilitate a comprehension of Figs. 67 and 68, the former showing a section (not strictly in one plane) of the ore-shoots in the government mine, and the latter a similar picture of the Struggl private mine. In the former, separate ore-bodies are observed to the distance of 500 meters (1640 feet) above the bottom of the valley, and in 1870 the continuous ore-shoots extended from 425 meters (1394 feet) above to 150 meters (492 feet) below that level, a total vertical height of 575 meters (1886 feet).

It will be seen that the several portions of the slopes descend more or less parallel with the stratification and the lime-slate contact, but with steps or offsets. The highest portion of the Abendblatt ore-shoot is about 300 meters (984 feet) in the foot-wall of the slate-contact; at greater depths there are portions 130, 150, 85 and finally 10 meters only (426, 492, 279 and 33 feet) from that plane.

It thus appears that the ore-shoots are approaching the contact in depth, and will probably follow it below. It is, therefore, not here the case that a particular layer in the limestone has favored the formation of spaces of dissolution. If that were true, the ore-body, notwithstanding the convergence of the seams southward, should maintain a more or less uniform distance from the contact, which it does not do, either in the section of Fig. 67 or in that of the Struggl mine, Fig. 68, where the opposite occurs, namely, the ore-shoots depart from the contact in depth. I must confess myself unable to explain these variations in the Raibl ore-shoots with the light afforded by the mine-workings down to 1870. But I am convinced that the explanation will be found by further thorough study. Meanwhile, I can only claim the credit of having placed the inquiry upon what I deem to be the true road, and express my regret that in the twenty years since the publication of my monograph on the Raibl deposits

no further progress seems to have been made in the interpretation of the very numerous analogous ore-deposits.

The North of England.—I cannot omit to mention here the region, classic in this respect, of the North of England. Lead-mining is actively carried on in the carboniferous limestone of Northumberland, Durham, Cumberland and Westmoreland, where the limestone alternates with sandstone and slate and occasional intercalated eruptives or their tufas. This formation is traversed and faulted by a variety of seams and veins; and the veins are generally richer where they are in the limestone. The thinner and more extensively faulted of the limestone strata are entirely severed, so that they appear in different horizons on opposite sides of the faulting-fissure. Where they are thicker or less widely thrown by the fault, however, limestone appears on both sides of the latter. It is obvious that an accurate picture of these conditions would furnish valuable data concerning the ore-genesis.

The several descriptions of the mines do not specify whether the ore of such veins as become rich in the limestone occurs in the fissures proper or outside of them in spaces of dissolution in the limestone. The latter is clearly the case in the so-called "flats." In certain horizons, where the seams encounter the soluble lime-stratum, the ore-filling departs from the fissure into the geodes of the rock, forming frequently very rich ore-bodies of highly irregular form, but flat, by reason of their following the soluble stratum. The ore-filling continues to a very uncertain distance from the fracture-plane, and is generally accompanied with frequent cavities, the walls of which are covered with crusts of calcite, blende and galena. Empty caverns also occur.* We cannot but recognize immediately in this description the type as to character and position of the Raibl deposits, the druses of which are here represented by the incrusted cavities. The empty caverns have doubtless been formed by subsequent processes of dissolution.

These phenomena occur in the North of England on a very large scale. Veins are mentioned which have been traced for several miles, and the connected subterranean channels of dissolution must be also of considerable length. The existence of laterally extensive ore-channels, and hence of an underground circulation of mineral

* See J. A. Phillips, *Ore-Deposits*, p. 180; also, D. C. Davies, *Metalliferous Minerals and Mining*, London, 1880, p. 216; and the works of W. Wallace, T. Sopwith, Westgarth Forster, C. E. De Rance, R. Hunt, etc.

waters not formerly suspected is thus revealed, and an entirely new light is thrown upon the so-called "ore-beds."

These observations are confirmed in another quarter by developments in Western North America, where very numerous ore-deposits are connected with limestone. It is impossible to bring forward here the whole of this material. I must limit myself to certain localities, which have been thoroughly studied and described in publications.

Leadville.—I will begin with Leadville, the recent blossom of the mountain-world of Colorado. I am, indeed, not personally acquainted with this locality, the importance of which was not recognized until after my visit to the United States; but my lively interest in it is testified by the article concerning it, which I laboriously compiled in 1879 from the incomplete data then available.* Later, when S. F. Emmons had finished his surveys, but before the publication of his epoch-making work,† I had opportunity to exchange views with him concerning the genetic condition, and to confess that I was unable to share his opinion as to the downward course of the mineralizing solutions—an opinion which was opposed to the then prevalent belief. The mine-workings have been greatly extended since that time, and Emmons's suggestion has been shown by several mining engineers,‡ on the basis of thorough studies underground, to be untenable; so that the Leadville deposits appear, as regards the origin of their metallic contents, to form no exception to the history of other similar deposits. I think Emmons himself must have acknowledged the force of these criticisms, which do not detract in the least from the merit of his accurate investigation of the district.

On the west slope of the Mosquito range appears a series of undulating Palæozoic strata, with heavy layers and intrusive masses of eruptive rocks, and traversed by numerous faults. This formation covers a large area, only a comparatively small portion of which, namely, the vicinity of Leadville, is ore-bearing,—a circumstance which of itself points to a local origin for the ore. As is well-

* "Leadville, die neue Bleistadt in Colorado."—*Oesterr. Zeitsch.*, 1879.

† "Geology and Mining Industry of Leadville."—*U. S. Geol. Survey*, Monogr. xii., Washington, 1886.

‡ F. T. Freeland, "The Sulphide-Deposit of South Iron Hill."—*Trans. A. I. M. E.*, 1885, xiv., 181; C. M. Rolker, "The Leadville Ore-Deposits."—*Ibid.*, p. 273; A. A. Blow, "The Geology and Ore-Deposits of Iron Hill."—*Ibid.*, 1889, xviii., 145.

known, the series of rocks has the following order downwards: white porphyry, blue limestone, gray porphyry, white limestone, lower quartzite,—which I will denote, for brevity, by their initial letters. The ore-deposits occur chiefly at the contact between the first two members of the series, below the WP. and above the BL. In the upper levels they are oxidized and chloridized (doubtless in this, as in other places, through the action of descending ground-water); in lower levels they appear in their original form as sulphides. That this was the condition in which they were originally precipitated, Emmons admits; only their position seems to him to exclude the hypothesis of ascending solutions. He says (*op. cit.*, p. 573).

"The principal water-channel at the time of deposition was evidently the upper contact of the blue limestone with an overlying porphyry; and from this surface they penetrated downwards into the mass of the limestone. It may be assumed, therefore, that the currents were descending under the influence of gravity, rather than ascending under the influence of heat."

But he omits to explain how he conceives it possible that mineral solutions descending by gravity, and hence certainly having been in contact with the surface-region, could deposit sulphides. Assuming such an explanation to be furnished by reduction through organic substances, the question arises whither such descending currents could go. Here the theory is in conflict with our conception of the underground circulations.

As A. A. Blow has shown, however, a leaching of the WP. cannot by any means have supplied the ore; for this rock is not at all decomposed, as in that case it must have been. On the other hand, there are found in the intrusive beds and dikes of the lower GP. various indications that this rock had more to do with the ore-deposition. Along these dikes lie the ore-shoots,—in other words, the channels in which ore was deposited.

It was at first tacitly assumed that the ore occupied the whole plane of the contact, although it was known that the richest bodies occupied particular zones in this plane. The importance of these ore-shoots was recognized later; and we may now consider the Leadville occurrence as presenting, not a single contact-deposit or ore-bed, but a complex group of ore-shoots, such as we have observed in other ore-deposits in limestone. These ore-shoots lie, in Leadville, at the contact between the soluble and the eruptive rock; while in Raibl they appear near the contact of two stratified rocks, one soluble and the other impermeable. The physical process

forming these ore-shoots was doubtless the same in both cases. The mineral solutions, ascending under pressure, and seeking a path to the surface, followed, as some would say, the line of the least resistance; or, as I would prefer to express it, there was established in the soluble rock a line of maximum circulation, resulting in the dissolving-out of a channel.

Such dissolution, however, occurred not only on the contact between WP. and BL., but also at other contacts. Thus L. D. Ricketts (Rolker, *op. c.*, p. 284) gives a section of a mine on Carbonate Hill, showing a second, deeper ore-horizon between the GP. (dike porphyry) and the underlying limestone. According to Rolker, the BL. of Fryer Hill was relatively thin, and has been replaced with ore and accompanying minerals, all but small remnants of dolomitic sand. These are generally above the ore, *i.e.*, along the upper contact, whereas, according to Emmons's theory, they should be replaced with ore.

The sections given by F. T. Freeland (*op. c.*, Figs. 1 and 6) show two ore-horizons, the thicker of which is below the WP., and the other below an intrusion of GP.; and Mr. Blow's sections from Iron Hill reveal similar phenomena (see Fig. 73, a section through the McKean shaft). The ore-shoots are, of course, irregular in form; but a main general direction can be recognized, which is eastward in Fryer Hill, but northeastward in Carbonate and Iron Hill, representing the course of the channel through which the mineral solutions circulated.

In the data at hand concerning the structure of the deposits, nothing is said of a distinct crustification. It is to be remembered, of course, that mining operations hitherto have been largely confined to the upper and decomposed zone, whereas this phenomenon, if ever so fully developed, would show itself clearly only in the undecomposed zone. When we read, however, of great "horses" of country-rock, encountered in the midst of the ore, we must believe that the deposit is due not so much to a metasomatic replacement of the limestone as to the filling of spaces of dissolution; and hence it should exhibit the characteristic sign of such a filling, namely, crustification. It seems to me that this point has not received the attention it deserves; and I hope that observations in the undecomposed ore-zones will give more definite data as to structure. It is difficult to believe that metasomatic processes could produce such pronounced ore-shoots as those described at Leadville.

Impressed by Emmons's views, and long before the connection

of the ore-deposition with the GP. of the dykes had been shown, I wondered, at one time, whether the ore might not have come somehow from the fault-fissures into the contact-channels. But Mr. Emmons pointed out to me that the faults contain only ore which has been dragged in from the pre-existing bodies, the formation of which was complete before the faulting took place.

Conditions analogous to those of Leadville are exhibited in most of the ore-deposits in limestone occurring in the American West. But, with few exceptions, we have only hasty descriptions of them, and sometimes nothing more than business "puffs."

Red Mountain.—A remarkable occurrence has been described in the Red Mountain district, Ouray County, Colorado.* In the midst of the deposits of the San Juan region, which are connected with eruptive rocks, appears a body of Mesozoic strata, carrying, at the contact of a quartzite with the underlying limestone, a deposit of the sulphides of iron, lead, copper, silver, and the products of their decomposition, rich in silver and somewhat auriferous (2110 to 3980 grammes of silver and 3 to 6 grammes of gold per metric ton, or 59 to 111 ounces of silver and 0.08 to 0.17 ounce of gold per ton of 2000 pounds). At certain points the ores extend far down into the limestone, and in the section shown in Fig. 74 the ore follows a fault-fissure through the whole thickness of the limestone into a second quartzite stratum below. The stratified formation is mostly covered with andesite, in which occur ore-bearing veins in fissure-form.

In the neighborhood, at Mineral Farm, another contact-deposit between limestone and quartzite is known, consisting of barite with argentiferous galena and tetrahedrite. Both the above deposits are but briefly described, and perhaps have not been extensively worked. Their conditions of position and the predominance of lead and silver-ores strangely remind one of Leadville.

In the adjacent Territories of New Mexico and Arizona, various copper-deposits occur in limestone, and at its contact with eruptive rocks; as, for instance (according to the outline-description of A. F. Wendt†), in the Clifton and Bisbee districts. The sections accompanying Mr. Wendt's paper remind me of some of the deposits described in my monograph, at Rézbánya, at Mědnorudjansk, and at Bogoslavsk in the Ural. Fig. 75 is an interesting section from

* G. E. Kedzie, "The Bedded Ore-Deposits of Red Mountain Mining District," *Trans. A. I. M. E.*, 1887, xvi., 570.

† "The Copper-Ores of the Southwest," *Trans. A. I. M. E.*, 1886, xv., 25.

the Clifton district, in Arizona, showing two steep ore-shoots, parallel with the felsite dike, and a flat one, parallel with the bedding.

Utah.—With respect to Utah, the paper of O. J. Hollister* gives a general survey of the deposits of the Territory, and mentions a number which occur in limestone. Some of those in central Utah I have had the opportunity to see personally, during the period when mining was still confined chiefly to the decomposed upper levels. I refer to the Prince of Wales and the Reed and Benson, in Big Cottonwood; the Emma and the Flagstaff, in Little Cottonwood; the Old Telegraph, in West Mountain, and the Hidden Treasure, in Dry Cañon district.

Palæozoic strata are here traversed by frequent eruptive dikes, and by two intersecting systems of faults. The ore-deposits, of varying thickness, in the limestone have, as a rule, the form of "chimneys," either lying flat, with the bedding, or standing steeply along the dikes and faults. This gave rise in the beginning (when the nature of the deposits was not understood, and the conception of a typical "lode" generally prevailed) to a series of disappointments and mistakes in mining, of which the history of the Emma mine furnishes an interesting example. Apparently the irregularity and the complications of these deposits came to be better known afterwards.

The (sometimes very rich) ores consist chiefly of sulphides of lead and silver, and the products of their decomposition. In some cases (*e. g.*, Hidden Treasure) cuprite occurs, with native copper; and in the Camp Floyd district cinnabar also is found.

Nevada.—In Nevada, adjoining Utah on the west, deposits of this class are likewise abundantly represented. I will mention only the two districts which have been most thoroughly studied, namely, White Pine and Eureka.

With regard to the former, the work of Arnold Hague (1870)†, demonstrating the peculiar character of the White Pine deposits, led me to seek for European analogues.‡ I found that, apart from the condition of the ores, which at White Pine are found in the oxidized and chloridized zone, there was an analogy with all the European ore-deposits in limestone, but especially with the conditions at Raibl.

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* "Gold- and Silver-Mining in Utah," *Trans. A. I. M. E.*, 1887, xvi., 3.

† "Geology of the White Pine District," *U. S. Geol. Surv. of the 40th Parallel*, vol. iii, *Mining Industry*, p. 409.

‡ F. Pošepný, "Das Erzvorkommen im White Pine District, u. dessen europäische Analogien," *Verh. d. k. k. g. Reichsanst.* 1872, p. 186.

Devonian limestones and calcareous slates are overlain at White Pine by Carboniferous clay-slates, sandstones and limestones; and the ores occur only in Devonian limestone and at its contact with the calcareous slates on a N. and S. anticlinal. The ores and the associated minerals (quartz, calcite, gypsum, fluorspar, barite, rhodonite, rhodochrosite, with the chlorides, bromides, oxides, and carbonates of various metals, especially silver, lead and copper) fill the cavities in the limestone and surround its fragments.

The various mines represent different stages in one and the same process. In the Eberhardt, two fissures crossing the anticlinal bound the ore-body (like the *Morgenblatt* and the *Abendblatt* at Raibl.) This consists of a lime-breccia (Kalktyphon), the fragments of which fit together, and are cemented by ore-bearing quartz seams. The Hidden Treasure mine contained the ore in geodes, at the contact of the limestone and slate. In the Aurora, the ore was in bodies stretching N. and S. In Bromide, Chloride and Pogonip Flats, the ores occurred in geodes and masses included in lime-breccia, in a zone parallel with the bedding. It is Arnold Hague's opinion that the Eberhardt mine probably represents the source of the ore-solutions which impregnated the limestone, wherever cavities existed, up to the level of the overlying calcareous slates, which were impermeable to the solutions. The slate-cover having been removed by erosion, the ores thus accumulated below it were exposed immediately at the surface; and the surprisingly large product of the district was derived from open cuts and shallow workings.

The other leading analogue in Nevada is found in the Eureka district, and was made widely known and practically significant by the law-suit between the Eureka and Richmond companies,* which involved the definition of a deposit not contemplated in the United States mining law. Similar difficulties have arisen under the old European mining codes. Such deposits were known in some districts of Europe, but they were not so widely distributed as the fissure-veins, for the conditions of which the ancient codes were framed. Conflicts were therefore inevitable. I will mention only Bleiberg in Carinthia (which presents some degree of analogy with Eureka) where, besides the general mining code, special statutes became necessary, departing from the usual rules with regard to prospecting and the location and the acquisition of claims.

* R. W. Raymond, "The Eureka-Richmond Case," *Trans. A. I. M. E.*, 1877, vi., 371.

The geological conditions of the district have been described in an elaborate monograph by J. S. Curtis,* based on the developments existing in 1882. Further knowledge may have been gained since, but, so far as I know, nothing later has been published. I made a brief visit to Eureka in 1876; but as no comprehensive maps of the mine-workings were then available, I could only observe in a general way the analogy with European deposits examined by me.

According to Arnold Hague,† the series here occurring of Prospect Mt. quartzite, Prospect Mt. limestone, Secret Cañon shale, and Hamburg limestone, is Cambrian. The ore is confined to the limestone first named, and in particular to a portion thereof on the NE. slope of Ruby Hill, enclosed between two fault-fissures. The features of the NW.—SE. ore-bearing zone are too variable to be indicated by a normal cross-section. Fig. 76 shows a generalized and Fig. 77 an actual section, as represented by Curtis.

The main fault-fissure separates, in the upper level, the massive limestone in its hanging- from the crushed, ore bearing limestone in its foot-wall. In the lower levels it shows, in the foot-wall, quartzite with intercalated "Lower shale," and in the hanging-wall, further down, shale and quartzite. An ideal restoration, above the present saddle of Ruby Hill, of the foot-wall rocks which have been removed by erosion, would bring to light a relative displacement of 150 to 600 meters (492 to 1968 feet), the indications being that the foot-wall has been lifted. This would explain at once the crushing of the limestone in the foot-wall, and the creation of a second fault near the contact between the limestone and the underlying quartzite.

The ores occur chiefly in the well-known form of chimneys and in individual masses, mostly interconnected by traces of ore, at least at the depth where the two faults come together. In the mines to the SE., about 180 meters (590 feet) from the Eureka-Richmond boundary, the fissures come together at the depth of about 400 meters (1312 feet), the line of their intersection thus dipping gently NW.

The ores encountered in the upper zones, above water-level, were, with the exception of a few insignificant remains of sulphides (mostly argentiferous galena), oxidized ores, such as cerussite and anglesite, chlorides, etc., carrying a considerable amount of silver and

* "Silver-Lead Deposits of Eureka," *U. S. Geol. Surv.*, Monogr. vii., Washington, 1884.

† "Abstract of Report on the Geology of the Eureka District," *Third Ann. Rep. of U. S. Geol. Surv.*, 1881–1882, Washington, 1883, p. 241.

a little gold. The present water-level follows approximately the line of intersection of the two faults, but the fact that oxidized ores have been found still deeper indicates that the water-level was once lower down.

It might consequently be expected that caves formed by the vadose circulation would also occur at considerable depths, especially as the whole wedge of limestone is traversed by ore-shoots, the oxidation of which would, of course, give occasion for cave-formations. The newly-formed caverns would often lie along the ore-channels, and especially in their upper portions. (See J. S. Curtis, *op. c.*, p. 100.)

Some of the irregularly distributed ore-bodies follow rather the quartzite-limestone contact; others rather the main fissures, with a NW. dip, like that of the limestone wedge. Of the two largest bodies, which have furnished the chief product of the district, the east ore-body exhibits a steep SE. pitch for nearly 400 meters (1312 feet), and the west ore-body, for nearly an equal distance, a flat NW. pitch.

In considering their structure, we must distinguish sharply between their original and their decomposed condition. The latter often hinders a clear recognition of the former. The strata-like deposits of cerussite and other products of decomposition mentioned by Curtis (*op. c.*, p. 98) are perhaps, like those in my sketch, Fig. 78, from the Old Telegraph mine, remains of the original crustification, and his statement (p. 104) that "where the ore is not oxidized there are no signs of a banded or concentric structure, and the phenomena observed point entirely to substitution of the sulphurets for country-rock," may thus be explained. In like manner his assertion, in the same place, that "the internal structure of the ore-masses in no way resembles those of Raibl," is so far correct that the original filling is at Raibl extraordinarily distinct, and at Eureka, on the contrary, perhaps, only obscurely traceable.

I personally saw in the Eureka mine some small ore-masses, which exhibited crustification, if not in a striking degree, yet sufficiently to be recognized by an impartial observer. Mr. Curtis himself (*op. c.*, p. 98) says that "rounded boulders of limestone as a nucleus" occasionally occur in the ore-mass, and that in a limestone-breccia "small masses of ore sometimes completely fill the spaces between the limestone walls,"—two phenomena which indicate crustification, and are explained by the hypothesis of a filling of pre-existent spaces.

A metasomatic removal of the limestone, such as has taken place

in the secondary calamine-deposits of Raibl, cannot well be supposed for the original ore-deposition at Eureka, but may have attended the formation of the secondary, decomposed products.

I believe that later mining in deeper zones has developed more clearly the structure of the original Eureka deposits, and that specimens of the ore have shown, after polishing, traces, at least, of crustification.

In short, I consider the original Eureka ores to have been deposited in pre-existing spaces by ascending mineral solutions, while their decomposition and the formation of the caverns are the effects of descending surface-waters.

I agree with Mr. Curtis that the ore-solutions ascended from the deep region through the "main fissure" (which has, in the NW. the character of a *Blatt* at Raibl, and in the SE. part of the district is filled with rhyolite), and that they formed and filled the ore-channels in the soluble, fissured limestone.

Missouri and Wisconsin.—We have dealt thus far with ore-deposits in mountain districts, where tilting and folding, as well as the occurrence of eruptives, betray a disturbance of the original relations of stratification. But there are also deposits in limestone in plateau-regions, where the strata show no considerable disturbance. Under this head two great districts deserve attention; namely, the lead-regions of Missouri and Wisconsin.

Concerning the former, we may refer to a number of more or less detailed descriptions.*

We have in this case not a perfect plateau, since here and there domes of the underlying Archæan come to the surface, as especially in the continuation of the Ozark mountains; but the predominant character is nevertheless that of a structural plateau. The ore-deposits, chiefly confined to the Silurian limestone, are in part primary xenogenous and in part hysteromorphous (débris) deposits; the latter, as is well known, consist of the detritus from the weathering and erosion of the outcrops of the former. In the former, we find all the phenomena encountered in the deposits of mountain regions. One of these is peculiarly developed, namely, the gently inclined

* J. R. Gage, "Lead-Mines of S. E. Missouri," *Geol. Sur. of Mo.*, 1873–4, p. 603, and *Trans. A. I. M. E.*, iii., 116.

G. C. Broadhead, "The S. E. Mo. Lead-District," *Trans. A. I. M. E.*, v., 100.

A. Schmidt and A. Leonhard, "The Lead- and Zinc-Regions of S. W. Mo.," *Geol. Surv. of Mo.*, 1873–4, p. 384.

A. Schmidt, "The Lead-Region of Central Missouri," *Ibid.*, p. 503.

cavities or ore-channels, shown in the Vallé and Bish mines of Jefferson and St. François counties, concerning which J. R. Gage has given some (unfortunately not very clear) notes and sketches.•

In the Vallé mines, a shaft 49.9 meters (164 feet) deep, situated 33.5 meters (110 feet) above the valley-bottom, encountered at three different depths, respectively of 44.5, 46.3, and 49.9 meters (146, 151 and 164 feet) flat-lying ore-channnels, 1 to 2 meters (3 to 6 feet) wide, which, winding in different directions, produce networks, connected at the intersecting points by chimneys from one level to the other. The cross-section of these channels in the horizontal limestone or dolomite contracts sometimes to a few square centimeters, or enlarges to several square meters, with a height of 3 to 4 meters (10 to 12 feet).

The original metallic filling was galena, pyrite and zinc-blende, but is already oxidized to cerussite, anglesite, smithsonite and calamine, which are accompanied with barite and a red clay. We are specially interested in the original structure of this filling; but this is not easily detected in the mere diagrams at hand.

Figs. 32 to 35 reproduce four of Mr. Gage's sections, the first three being Figs. 17, 18 and 19 of his paper in these *Transactions*, and the fourth, Fig. 72 of his article in the report of the Missouri survey. They indicate for both the metamorphosed and the original mineral crusts a prevailing horizontal position, so that we might conclude that the deposits took place in cavities, the upper portions of which were filled with gas only. A very peculiar formation is the red clay which in some instances covers the walls of the caverns and surrounds on all sides the central filling. The data at hand afford no clue to its origin.

Mr. Gage's description of Fig. 35 (*op. c.*, p. 618) is as follows:

"Fig. [72] represents the occurrence of these minerals. The solid limestone contains a fissure, entirely filled with minerals and gangue. The minerals are completely enveloped by the red clay. Above are two thin folds of silicate of zinc, separated from each other and from the limestone by the red clay. The folds of the zinc-ore are sometimes perfectly solid, being from one to six inches thick, and consisting of alternate layers of the same material in very compact folds; again, the mass of zinc-ore is from one to six inches in thickness, but, instead of being dense, consists of a thin crust, with a cavity, whose interior walls are lined with beautiful, brilliant crystals of the silicate and occasionally the carbonate of zinc. More rarely, crystals of galena occur in the cavities, but, in this case, are invariably covered with a thin coating of the silicate; and not infrequently portions of the cavities are partly filled with red clay, highly impregnated with oxide of iron, and having the appearance of a highly-decomposed brown hematite. Occasionally, heavy spar (barytes) lies in a dense mass in close contact with the zinc-

ore; but more frequently it is associated with the galena. Often, but not invariably, immediately below the folds of zinc-ore, occur irregular masses of the zinc-ore in the crystallized form, as pseudomorphs of galena," etc.

All the doubts which arise concerning the mode of this formation would probably be solved by a series of *objective* pictures of it; and it is to be hoped that an occurrence so interesting theoretically will be accurately recorded before it is too late.

The deposits occurring near the "islands" of granite and porphyry, have special interest. While the Silurian limestones of the surrounding country, farther from these islands, present chiefly only lead- and zinc-ores, other metals, such as copper, cobalt, and nickel, occur as the Archæan foundation-rocks are approached; and this circumstance is, to my mind, an indication that the source of the lead-deposits also is to be sought in depth.

Mine la Motte.—As an example, I may cite the district of Mine la Motte, to which I once made a brief visit. The rock here is usually the same, namely, a Cambrian dolomite, containing, however, sandy portions and a clayey stratum characterized by numerous fossils (*Lingula*). The ore occurs predominantly as an impregnation in the rock, more concentrated in a given zone. The so-called sandstone does not here, as in other instances, cut off the impregnation; it is, in fact, only a sandy limestone and dolomite, and its carbonates can be replaced by ore as well as those of adjoining strata.

I thought that I noticed in the open workings called the Jack and the Seed-tick diggings a very remarkable phenomenon; namely, the ore-impregnation in the almost horizontal stratified rock was conformable not to the bedding but to planes crossing it at a very acute angle (about 10°). A pretty long terrace was exposed; and the impregnation-planes cut pretty regularly through the sandy dolomite also. This appearance indicates plainly a later formation of the ore, independent of the deposition of the rock-strata; and one is almost involuntarily forced to believe that it was the former ground-water surface which formed the cavities to be impregnated. But it was, and is, inconceivable to me how these cavities could be filled with sulphides; and I can only urge that occurrences of this kind should be subjected to a more thorough study than it has been in my power to give to them.

Wisconsin.—In Wisconsin, and in parts of Iowa and Illinois, there is an extensive true plateau, the calcareous members of which contain many and various deposits of lead- and zinc-ores. An excellent monograph concerning them, by my esteemed friend, Prof. J.

D. Whitney,* is at hand. The author seeks to show that the mineral solutions depositing these ores came from above, not from below. He appeals to the circumstance that of the two stratified formations, the upper and the lower Magnesian limestone (underlain by an upper and a lower sandstone, respectively), the ores occur chiefly in the upper, and only seldom, and in small quantity, in the lower; while the two sandstones (the lower of which is assigned to the Potsdam) do not reveal any traces of ore, as they should do if the solutions had come from below. I confess that this conclusion is not obvious to me. There may have been a passage through these sandstones at a distant point, not yet exposed; and the mineral solutions may have found or created spaces in the soluble rock.

The argument that the ores must have come from above because it has not been possible to discover, in the Wisconsin region, fault-fissures and eruptive dikes, such as have brought up similar ores in the north of England and other places, seems to me likewise inconclusive. And as little can I accept the explanation of an occurrence near Dubuque, discovered by T. Levens and described by Whitney (*op. cit.*, p. 391 and Fig. on p. 392), which I reproduce in Fig. 79. The fragments of galena, crusted with cerussite, which hang from the roof of a natural cavern, are taken as a proof that the solutions which deposited them must have come from above. But a continuation of this cavern is indicated in the bottom, filled with clay, mixed with scattered pieces of galena. In my opinion, this was doubtless originally the filling of a vertical fissure, which was enlarged by the ground-water, as indicated by the dotted line. The symmetrical crusts, as I suppose, of that filling were in part broken up, and fell into the clay accumulating in the space below; while the upper part of the filling remained attached to the rock of the roof.

3. Metamorphous Deposits.

Metamorphism has been most truly defined by A. de Lapparent as the sum of the chemical changes undergone by the sedimentary rocks after their deposition. General or regional metamorphism, affecting the rocks over wide areas, is distinguished from local or contact-metamorphism, caused in certain groups of strata by eruptive intrusions. In studying the occurrence of useful minerals, we occupy rather the local standpoint, and start with an assumed original

* *Report of a Geological Survey of the Upper Mississippi Lead-Region*, Albany, 1862.

condition of the rock, though its really original character may not always be demonstrable—understanding thereby, for our purpose, a so-called typical condition, usually shown at most places where the rock occurs.

We distinguish the replacement of some constituents of a compound rock, for which the term "impregnation" is more appropriate, from the replacement of the whole homogeneous mass by metasomasis. But since every rock undoubtedly contains small primitive cavities, it is difficult, and sometimes impossible, to decide whether a new, xenogenous substance has not been deposited in such pores; and a case of this kind would fall under our notion of impregnation. The new substance may indeed have found entrance through the pores, if the mineral solutions were under sufficient pressure to overcome the friction of their walls, at least in the line of least resistance; and these solutions, thus introduced, may attack and replace one or another element of the rock. The entrance of such solutions will be greatly facilitated by the fissuring of the rock, whether by internal or external forces. We find in connection with ore-veins, and also with the thinnest mere seams, an impregnation of the country-rock, which Cotta has called subordinate or dependent (*unselbständige*) impregnation.

The particles of certain substances possess a peculiar mutual attraction. In the sandstone of Fontainebleau occur aggregates of calcite crystals, which have come together in spite of the separating medium of sandstone; and in a similar way, as we have seen, another substance of strong crystallizing power, namely, galena, forms, in the pipe-ores and script-ores of Raibl, crystalline masses, in spite of the intervening diaphragm of a foreign medium.

In like manner are formed the so-called concretions, the calcareous and marly masses (*Lösskindlein*) in the Loess, and the *Marleker* of the ancient Scandinavian beaches. For the formation of the former, occasion was given by decaying plant-roots; for that of the latter, by various animal remains, mussels, fishes, etc. In Norway, they have preserved a complete fauna of the Glacial and post-Glacial epochs.

Similarly, we find in some spherosiderite concretions of the Saarbrücken coal-basin the remains of fishes. A discernible nucleus is not always found in such concretions; sometimes no cause for this peculiar formation can be discovered. The concretions occurring in stratified rocks are usually lenticular, comprising portions of several similar strata. Even spherical forms, resembling pisolites, occur.

If we imagine, for instance, spherosiderite concretions formed closely side by side in one stratum, we shall have a regular bed of clay-ironstone. Leaving out of view the agency of fissures, or contacts with intruded rocks, impregnations following certain strata may be formed, constituting a second kind of ore-beds. A third kind may result from the more or less complete replacement of the original rock, especially when the latter is a soluble precipitate, like gypsum or limestone. In thick limestone formations the ore-beds occur at the contact with insoluble rocks, as at Rodna.

In all these cases the deposits have the form of a bed, but the ores rarely cover the whole contact-surface, occupying, on the contrary, only certain zones of it. In other words, in these as in other deposits, ore-shoots occur.

Much more complicated relations result when the mineral solutions ascend along structural fissures and rock-contacts; and in order to a comprehensive description of this suite of phenomena, it will be well to consider first the simpler conditions obtaining in soluble rocks, and afterwards the more complex occurrence of such deposits in crystalline and eruptive rocks. We will, therefore, review the metamorphous deposits as they occur in (*a*) distinctly stratified rocks; (*b*) soluble precipitates; and (*c*) crystalline schists and eruptive rocks.

a. Metamorphous Ore-Deposits in Distinctly Stratified Rocks.

We find in unquestionable sediments not only metallic oxides and salts, but also sulphides, in the form of ore-beds which, by reason of this stratigraphical relation, have been held to be of contemporaneous origin, that is, idiogenous. As a consequence, it has been necessary to assume that they were precipitated in a sea-basin, in which, before and after their precipitation, only barren sediments were deposited. These metals must, therefore, have been dissolved in the water of the basin, and that in very large quantity, as indicated by the frequently great thickness of the ore-beds. But for such an assumption we have no present analogy.

The Deposition of Ores from Sea-Water.—In this particular, however, we have to do rather with suggestions than with demonstrations of fact. So far as sea-water is concerned, traces of metals have been found in the water itself, in the ashes of marine plants, and in the solid constituents of marine animals, for instance, corals, by Malaguti, Bibra, and Forchhammer.* Traces of silver, iron,

* G. Bischof, *Chem. u. Phys. Geologie*, vol. i., Bonn, 1843, pp. 445–447.

and manganese were detected in the water, and lead, zinc, cobalt, and nickel in the marine organisms; and since there are in sea-water small amounts of hydrogen sulphide, Bischof considers the deposition of metallic sulphides from the sea to have been possible. He observes (*op. cit.*, p. 432) that the occurrence of metallic sulphides in sedimentary rocks, such as that of copper and silver sulphides in *Kupferschiefer*, or that of lead sulphide in *Buntsandstein*, may be thus explained; and even indulges (p. 836) in the following teleological conclusion:

"Since it cannot be doubted that the rivers flowing into the ocean bring with them metallic salts, though in very dilute solution, it seems a wise arrangement that in the hydrogen sulphide of sea-water a precipitant is presented to throw down the smallest minima, and thus to prevent the gradual accumulation of substances *so injurious to animal life*."

Of the various metals dissolved in sea-water, iron is least injurious to animal life. Indeed, animal life assists, in the so-called lake-ores, the segregation of this metal. Moreover, the precipitation of ferrous and ferric oxides from concentrated solutions is probable, so that a precipitation of iron-ores directly from sea-water seems to be established as a possible origin for some iron-ore beds.

But the conveyance of metallic salts by rivers to the ocean and the formation of hydrogen sulphide in sea-water are unquestionably continuous; and the precipitation of metallic sulphides must, therefore, have taken place uniformly in all sediments and precipitates of the ocean; whereas, we find the ore-beds in fact only in certain strata. If these are to be thus explained, we must assume that the ocean was at certain periods much more strongly impregnated with metallic salts —a scarcely tenable hypothesis as applied to the mighty deep,—or we must suppose with Carnall, as H. Hoefer has recently done,* a subsequent re-deposition of the primitive metallic salts, contained in minute quantities in the sea-deposits—in other words, their solution and re-precipitation at certain horizons. Hoefer cites the lead- and zinc-deposits of Upper Silesia and other districts, which occur in marine Triassic limestones. He assumes the maintenance of uniform horizons by these deposits to be demonstrated, but points out that some of these horizons were already ore-bearing when first formed.

In short, a number of investigators have adopted the hypothesis of an original ore-deposition from the ocean, without giving any

* "Die Entstehung der Blei-, Zink- u. Eisenlagerst. in Oberschlesien."—*Oesterr. Zeitsch. f. Berg.-u. H-wesen*, 1893, xli., p. 82.

other reason than the observed relations of stratification. Yet, in a considerable experience with ore-deposits in marine limestones, I have never been able to find genuine ore-beds among them, but always only ores of subsequent introduction; so that I feel warranted in believing that such ore-beds proper do not exist.

As to the primitive ore contained in marine sediments and precipitates, innumerable chemical analyses, especially of limestone, have failed to show the metallic traces which, according to the above hypothesis, should be present. For this reason, as I have already observed, even Sandberger did not venture to derive the metals from the limestone, preferring, for instance, at Raibl, to look to the overlying slates.

The maintenance of certain ore-bearing horizons was set up by A. von Groddeck, to render more plausible the notion of a direct deposition from the ocean; but I do not believe it possible to prove such an identity of horizon for different ore-deposits. Similar ores and stratigraphical conditions are not confined to the Trias. On the Rhine, in England and in America they occur at much lower horizons in the Palæozoic rocks. Even in Carinthia the ore-bearing limestones of the richest deposits do not occupy the same horizon. That of the Raibl slate is very different from that of the Bleiberg slate (carrying *Ammonites Aon*), and the deposits in these localities are by no means beds, but, as I have shown, channels in the limestone, filled with ore.

Ore-Deposition in Fresh Water.—The demonstration of direct ore-deposition in fresh-water strata encounters the same difficulties, though it may be supported by the same chemical speculations. Here the hypothesis is favored by the analogy of the lakes of regions without drainage to the sea, in which the salts brought in by rivers are necessarily concentrated by evaporation. But since organic life is restricted in these salt lakes to a few animal species, the analogy can have but a limited application. Moreover, it would be necessary to suppose cataclysmic changes, like the interposition of a period of no drainage in the midst of an epoch of fresh-water sedimentation.

Without the assumption of such cataclysms, I do not believe that the Mansfeld *Kupferschiefer*, in which the organic (fish) remains can be traced continuously from foot- to hanging-wall, could be explained in this way. It deserves mention, that some of the earlier geologists, like Freiesleben, accepted the sometimes contorted attitudes of the *Palæoniscus* in the *Kupferschiefer* as a proof of contempora-

neous ore-depositions, and alleged that these fishes had been thrown into violent contortions by the copper-solution, in which condition they died and were buried in the sediment. The *naiveté* of this diagnosis (which, nevertheless, some modern writers have not hesitated to repeat), is evident. Contorted fish-remains occur in other formations outside of the *Kupferschiefer*, and clearly show the advanced state of decomposition in which the bodies reached the sediments.

The Kupferschiefer of Mansfeld.—The Mansfeld *Kupferschiefer*, as is well known, is a thin bed of bituminous slate, lying between the Permian sandstone below, and the marine member of the same formation, the *Zechstein*, above, and containing sulphides of copper, silver, lead, zinc, antimony, mercury, nickel and cobalt. The copper amounts to 20 to 30 kilograms (44 to 66 pounds), and the silver to 125 to 150 grammes (4 to 5 ounces, Troy), per metric ton of 2204 pounds. In polished sections, the ore can be seen in thin leaves lying between laminæ of slate, and often accompanied by gypsum. But the same ores occur in scattered bunches in the sandstone below, and small bodies of redruthite are found in the limestone above.* This circumstance alone, that ore occurs also in the marine limestone, above the fresh-water *Kupferschiefer*, is unfavorable to the contemporaneous origin of ore and rock.

Kupferschiefer in Thuringia and Bohemia.—The same bituminous slate occurs in the Thuringian forest on the south slope of the Hartz, and in other points a considerable distance away. It must therefore have been deposited in a large basin. But it is a question, whether it anywhere carries ore and deserves the name of *Kupferschiefer*.

In NE. Bohemia, the same Permian slate, with almost the same fossils, is widely distributed, but without the marine member which covers it in Germany. The Permian of Bohemia carries copper-ores in many places; and in one locality, namely, at Hermannseifen, these ores occur in the bituminous slate, which might properly here be called *Kupferschiefer*. I had opportunity in 1858 to examine the mines. The richness in metal was not unsatisfactory; but there was much complaint of the numerous faults which seriously enhanced the difficulty of mining.

Precisely the same difficulty exists at Mansfeld and in the Thuringian forest, as Cotta (*op. cit*, p. 109), reports in part as follows:

"The fault-fissures themselves, are, however, rarely ore-bearing, yet often seem

* See Groddeck's *Lagerstätten der Erze*, p. 94, and Cotta's *Erzlagerstätten*, Pt. II., p. 106.

nevertheless to have influenced the ore-bearing character of the strata traversed by them. This influence is shown in the increase or diminution of the proportions of ore, not only in the immediate neighborhood, but sometimes also for a considerable distance, even as far as the next master-fault. It is shown also in the transfer of the metallic contents from one stratum to another."

This and other observations concerning the influence of the faults upon the ore-distribution bear decidedly against the contemporaneity of the ore-deposits, and in favor of a later introduction of ore through the fault-fissures.

But this conclusion becomes much clearer upon a consideration of the remaining occurrences. Thus, according to Cotta (*op. cit.*, p. 74), the *Kupferschiefer* at the edge of the Thuringian forest is not so rich in ore as on the southern border of the Hartz. More important than the copper-slate itself are the fault-fissures which traverse the whole group of strata, but only carry ore in certain zones in which they intersect certain strata—the *Kupferschiefer* among them. "Strange to say," observes Cotta, "near Camsdorf it is almost exclusively where the *Kupferschiefer* has suffered such disturbances that it is rich enough to repay mining." In speaking of Riegelsdorf he says, "The cobalt-ores have in some cases made their way from the veins into the country-rock."

Westphalia.—At Stadtberg (*op. cit.*, p. 161), in Westphalia, there are even several copper-bearing strata, and these are cut by copper-bearing veins. At Bieber, veins traverse the whole group of strata into the underlying mica-slate, and "the irregularly distributed ore occurs, strange to say, chiefly interleaved in the mica-slate, and not, as in the Hartz and the Thuringian forest, in the horizon of the *Kupferschiefer;* while, on the other hand, the impregnations from the veins have penetrated chiefly the bituminous marly slate."

In consideration of the expressions partly quoted *verbatim* above, it is difficult to see how there can be any doubt of the secondary nature of the ore-deposits in the *Kupferschiefer* throughout. Yet Groddeck* has reproved me for coming to this conclusion. He says himself† expressly (evidently having in mind the typical Mansfeld occurrence):

"The ores were laid down contemporaneously with the slime-deposit, the bituminous marly slate as the ore-matrix." . . . . "It is entirely impossible that the ores could have entered the bed somehow from the fissures, at a later period, after the covering of the marly slate with more recent rocks. If we assume that the ore-

* "Bemerk. zur Classification d. Erzlagerstätten," *B. u. H. Ztg.*, 1885, xliv., p. 247.

† *Erzlagerstättenlehre*, p. 301.

solutions were introduced through the fissure faulting the bed, it remains inconceivable why the filling of metallic sulphides, through a field of many square miles, should be uniformly and exclusively confined to the stratum of marly slate, about ½ meter (19.5 inches) thick, and should not also occur more or less near the fissures in the strata above and below, there being in these no lack of carbonates and bituminous constituents, available as precipitants of the solutions—the *Stinkschiefer*, for instance, lying not far above the *Kupferschiefer*, being rich in such substances."

Groddeck here overlooked the principle, elsewhere urged by him, that a single link in a whole chain of phenomena should not be exclusively considered. He contemplated only the special development at Mansfeld; assumed, moreover, similar developments for many square miles, which show in fact many variations, and did not take into account the circumstance that when the *Kupferschiefer* is not cut by fault-fissures, it is also not valuable for mining. Finally, he was unacquainted with the theoretically important occurrence of the *Kupferschiefer* in Bohemia. The contemporaneous origin of the ore and rock at Mansfeld was with him, so to speak, a dogma, as may be perceived in some of his expressions (*op. cit.*, p. 302):

"The local ore-bearing character of the foot- and hanging-walls of the *Kupferschiefer*-bed is no proof to the contrary, for it is always confined to the immediate neighborhood of the bed."

"Into the sea, rich in fishes and plants, from which the marly slate was deposited, flowed abundant metallic solutions, which killed the organisms and were themselves reduced by the products of decay."

The first of these propositions becomes logical if it is simply reversed in sense; and the bold hypothesis of the second indicates a doubt which the author is seeking in this way to set at rest. His statement (p. 302):

"It is not to be doubted that metallic sulphides may be formed at the earth's surface, under ordinary pressure and temperature, beneath a water-covering which excludes the air,"

is quite correct; but when he adds:

"And there is therefore nothing to prevent the belief that sulphuretted ores could be precipitated at the same time with the deposition of sedimentary rocks,"

it is necessary to add, "*provided* the metallic salts were present in the sea-basin."

This is, indeed, the center of gravity of the whole question; and, as I have shown, the proposition presents an improbability.

Various other peculiarities of individual ore-occurrences are cited in favor of the theory of contemporaneous origin; but all of them, when impartially weighed, are equally consistent with a different genetic explanation, and fail to be as significant as the Mansfeld type for the theory in question.

The Copper-Sandstones of Bohemia.—In Bohemia and on the west slope of the Urals, the copper ores of the Permian strata occupy by no means a continuous horizon, but occur as impregnations in different beds, beside, above, or below one another. There are here, as in the German *Kupferschiefer* mines, fault-fissures which may have served as ore-conduits; and in these regions the notion of a primary sedimentary origin of the ores has not been so often suggested. At some places in Bohemia, as, for instance, at Starkenbach, melaphyrs appear above the ore-beds.

In almost all these, as in many of the German deposits, the copper sulphides, especially redruthite, occur in the neighborhood of plant-remains; and oxidized copper-ores predominate, as a rule, in the ore-beds in sandstone.

Not only Permian, but also Triassic and still more recent sandstones, exhibit analogous deposits, containing lead, silver, and antimony, as well as copper. At Boleo, in Lower California, such an ore-deposit is known in Tertiary strata. The range of illustrations, therefore, is an extensive one. I can mention but a few.

St. Avold.—Concerning the copper-ores in the Triassic sandstone of St. Avold and Wallerfangen, Groddeck gives (p. 99) a brief description, based on an article by C. Simon.* The sporadic ores are most abundant in the vicinity of fault-fissures; but only single strata are rich, while other porous layers near by are barren of ore. The ores extend in zones, independent of the course of the fissures, which they often even cross at right-angles. These two features are said to prove the contemporaneous origin of the ore and rock, "since the enrichment of a zone where it is cut by the fissures can be simply explained by the leaching-out of ores in higher strata, and their re-deposition in or near the fissure." I must confess that this explanation is not satisfactory to me. Figs. 80 and 81 illustrate the situation.

At Bleiberg, in St. Avold, concretions of galena, of pea-size, occur in the sandstone; and below the same layer considerable masses of solid galena are encountered.

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* *Berg u. H. Ztg.*, 1866, xxv., p. 412.

*The Lead-Deposit of Mechernich, near Commern.**—This deposit has a special interest in this connection, since it consists of sandstone of considerable thickness, somewhat porous, and impregnated with small concretions of galena (*Knoten*), which have often been considered as contemporaneous in deposition with the rock. The district, situated on the north edge of the Eifel Mountains, embraces a zone about 7 kilometers (4¼ m.) long, through Call, Keldenick, Mechernich, and Strempt. Already in the Roman period, at the Tanz Mountain, near Keldenick, mining was done upon galena veins in the Devonian limestone, which is overlain by the sandstone and conglomerate of the variegated sandstone formation. The conglomerate covering the sandstone has the name of *Wackendeckel*, and sometimes carries ore, the cement between its pebbles being traversed by galena and oxidized products, especially cerussite, which were formerly mined.

It is at present the sandstone, impregnated with galena concretions (*Knoten*) to the extent of 5 to 30 kg. (0 5 to 3 per cent.) of lead, and 1 to 6 grammes (0.03 to 0.18 oz. Troy) silver per metric ton of 2204 pounds, which is the principal basis of an extensive mining industry.

The thickness of this *Knotensandstein*, the number of its intercalated conglomerate layers, and the richness in ore of each stratum vary greatly, as do also the number, direction and manner of throw of the fault-fissures by which it is traversed. Fig. 82, representing the stratigraphy SW. of the boundary of the mining grant at Meinerzhagen, shows the irregularity of the displacements. Within the grant, the several *Knoten*-layers are united into a single bed, about 22 meters (72 feet) thick, separated by a conglomerate layer from the Devonian rocks below, and overlain by another conglomerate, the so-called *Wackendeckel*, above which is the barren red sandstone. In general terms, there lies here upon an impermeable floor a pervious group composed of sandstones and conglomerates, overlain by argillaceous red sandstone and loam.

The *Knoten*, never larger than peas, exhibit, when prepared in thin sections and mounted in Canada balsam, crystalline aggregates of galena, in which the crystal-faces are turned outwards, away from the center; that is, they are by no means composed of spherical masses, as they seem to the naked eye to be, when examined as

* Baur, "Das Vorkommen von Bleierzen am Bleiberge bei Commern," *Eschweiler Pumpe*, 1859.

F. W. Huperts, *Der Bergbau u. Hüttenbetrieb des Mechernicher Bergw. akt. Vereins*, Köln, 1883.

Ellsworth Daggett, "The Lead and Silver Works of the Mechernich Mining Company," *E. and M. J.*, xxiii., 1877, pp. 120, 136, 168.

they come from the crumbly rock. Their distribution in the sandstone generally follows the bedding; but in the neighborhood of the cross-faults I observed an accumulation of *Knoten* in zones parallel to these steep fissures. Moreover, I found occasionally in the fissures themselves threads of galena and pyrite; and hence I do not doubt that the ore-deposition here was secondary, and proceeded from the fissures. To gain a clear view of this question, it is necessary to include the ore-occurrence in the conglomerates, where, as already observed, it impregnates the material cementing the pebbles, and also, the nearest ore-occurrence in the Devonian limestone, where it appears in fissure-veins.

In my opinion, the loose, pervious sandstone, enclosed between less permeable strata, and cut by many fault-fissures, was impregnated by ascending springs, which employed it as a path in their circulation; but it cannot be determined what constituted the centers around which the galena concretions are formed. May it have been minute particles of feldspar, such as are still occasionally visible; or was it organic substances, which have now entirely disappeared?

Freihung.—Perhaps additional hints may be furnished by the mines of Freihung in the Bavarian Upper Palatinate, which Cotta considers analogous to those of Mechernich. Here galena and cerussite impregnate the *Keuper* sandstone, the steep dip of which they share. At the Nuremberg Exposition of 1882, maps, ore- and rock-specimens from the mines of the Bavarian Lead-Mining Co. were exhibited. Fig. 83 is a section through the Vesuvius mine. I was struck with numerous specimens of tree-stems changed to galena; and, coming subsequently into possession of such a specimen, I had a polished section prepared from it. The pieces of these stems exhibited are about 20 centimeters (8 inches) long, and elliptical in sections, say 5 to 7 by 10 to 15 centimeters (2 to 3 by 4 to 6 inches.) The fiber and the annual rings could be recognized on the surfaces of fracture, but were extremely plain in the polished section. Indeed, they were indicated by the cleavage of the specimens. I have thin slivers, 2 to 4 mm. (0.08 to 0.16 inches) in diameter and several centimeters long, representing the fibers of the original wood. The former bark is replaced first by a zone of pyrite, and then quartz grains cemented with pyrite. I do not know that the determination of the species of the wood has been attempted, but I think it should be approximately practicable. Fig. 84 is a diagram of the section of such a stem altered to galena.

Certainly we have here another instance showing that the organic substance attracted metallic solutions and reduced them to sulphides, and this, under conditions similar to those of Mechernich. The latter occurrence may, therefore, be most simply explained by the hypothesis of an organic substance, distributed through the rock, which reduced the circulating mineral solutions and occasioned the formation of the concretions (*Knoten*).

Silver Reef.—Accustomed as we are to find silver associated with lead-ores, we are surprised by the occurrence, in the Silver Reef district of Utah, in probably Triassic sandstones, of silver accompanied by copper. So far as can be gathered from the various descriptions at hand,* there occur here two beds (the outcrops of which are called "reefs"), which carry silver, either exclusively or with a little copper—the former usually as a chloride, but sometimes native; and the latter in the ordinary oxidized ores. It may be reasonably inferred that the deposit has been thus far exposed in its upper, chloridized, and oxidized zones; and that in depth it would be found to contain sulphide-ores. Whether such depth has been reached by the miners I do not know.

The beds consist of red and gray argillaceous sandstones and arenaceous clay-slates, between the laminæ and in the cross-joints of which the ores occur, being the more concentrated, the more highly fissured the condition of the rock. Although traces of silver are found throughout the bed, the pay-ore is confined to separate chimneys or channels, which descend on the true dip, or pitch obliquely to it. The richest bodies are said (Rolker, *op. c.*, p. 25) to be most frequently found above a certain thin, very clayey, sandstone stratum. Very often, but not always, the silver-ore is accompanied by carbonized vegetation, such as trunks and stems of trees, and reed-like plant-remains, which are covered and impregnated with horn-silver. The copper- and silver- ores, while occurring to a certain degree in association, seem to exclude one another, and are seldom found in actual mixture.

The same sandstone which here carries ore is said to be represented in the plateau cut by the Colorado river; but there the strata

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* "The Silver Reef District, Southern Utah," (by R. P. Rothwell or Thomas Couch ?), *Eng. and M. Jour.*, xxix., 1880, pp. 25, 45, 59, 79, 351.

C. M. Rolker, "The Silver-Sandstone District of Utah," *Trans. A. I. M. E.*, ix., 21.

J. S. Newberry, "Report on the Properties of the Stormont Silver Mining Co.," *E. and M. J.*, xxx, 1880, p. 269.

are horizontal and undisturbed, whereas in the ore-district they dip rather steeply, are much disturbed, and are in many places covered with eruptive rocks, including basalt. This neighborhood to eruptives renders it probable that here, as in so many other places in Western America, the ores have been introduced by the mineral springs which usually follow eruptive activity. Rothwell, Couch, and Rolker are of this opinion; whereas, Newberry is inclined to suppose a contemporaneous origin of ores and rock. The principal arguments for his view are, the alleged great area of silver-bearing Triassic strata in that region; and the circumstance that the richest bedded and lenticular ore-bodies are enclosed in almost impermeable slate-clays, which would not have permitted a subsequent entrance of the mineral solutions. Neither of these statements disproves the secondary origin of the ores. They could have been deposited in any given way on a large scale, as well as a small one; and that the almost impermeable slate-clays did not prevent the entrance of solutions is proved by the subsequent alteration of the original filling to chlorides and oxides.*

Moreover, the deposits are not regular strata but chimneys and channels in parts of strata, and this character, which they possess in common with so many other deposits, should be decisive in favor of their secondary origin—a conclusion which, in my opinion, is always reached when observations are not confined to single localities, but extended over whole series of analogous phenomena.

Copper-Deposits of New Mexico and Arizona.—Traces of similar ore-distribution in sandstones seem to be not infrequent in the American West. Thus F. M. F. Cazin† says of the copper-ores of the probably Triassic sandstones of the Nacimiento mountains in NW. New Mexico, which J. S. Newberry had described in 1860:

"The ore occurs nearly exclusively as the petrefaction of the leaves, stems, limbs and trunks of palms. Frequently the ore is coated with a film of jet or coal. It is always easily separated from the rock. The ore is predominantly erubesite, copper-glance and melaconite. It appears to be distributed all over the massive stratum, but is more densely collected on seams and cleavages, in some instances forming a single layer of petrified parts of palm-wood."

This occurrence, which is analogous to those in Bohemia and in

* Compare F. M. F. Cazin, "The Origin of Copper- and Silver-Ores in Triassic Sandrock," *E. and M. J.*, xxx., 1880, p. 381.

† "New Mexico *vs.* Lake Superior as a Copper-Producer."—*E. and M. J.*, xxx., 1880, pp. 87, 108.

the province of Perm, was declared to possess great economic importance. Its later developments are not known to me.

W. P. Blake* has described an analogous occurrence in the sandstones and conglomerates overlying the granites in Copper Basin, Yavapai county, Arizona, where the copper-ores are found unconnected with any organic substances. In the underlying granite, however, there are fissures filled with copper-ores. He thinks it probable that copper sulphides circulating in the highly permeable sandstone were precipitated as carbonate by carbonate of soda, while the resulting sulphate of soda escaped in solution, to be concentrated by evaporation, forming deposits of thenardite, which is common in Arizona.

Lower California.—At Boleo, opposite Guaymas, on the peninsula of Lower California, E. Fuchs† has described a remarkable deposit of copper-ores in Tertiary sandstones, conglomerates and tufas, which must be mentioned under this head. The east slope of the (mostly eruptive) mountain range extending through the peninsula is a plateau, gently descending towards the Gulf of California, and cut by precipitous cañons. It is formed of strata containing characteristic Miocene fossils. Tufas decidedly predominate, and the series contains three or four copper-bearing beds, covering a large area, and out-cropping at many places in the cañons. These lie immediately upon conglomerates of pebbles of eruptive rock (different and characteristic for each horizon) and are overlain by clayey tufas. The whole is traversed by several fissures, of which the largest and most important is a fault-fissure, occurring at the western border of the district and striking about parallel with the sea-shore.

In the ore-beds above the ground-water level, disseminated oxidized ores prevail, such as black oxide of copper, and the protoxide, with atacamite ($CuCl_2 + 3\ CuO + 3H_2O$), azurite, malachite and chrysocolla, with crednerite ($2\ Mn_2O_3$, $3\ CuO$). In the second ore-bed (counting downwards) there are peculiar globular concretions, like oölites, of copper oxide and carbonate, sometimes several centimeters in diameter, which are locally called *boleos*, whence the name of the district. Though greatly interested in this type of ore, I have never succeeded in getting specimens, and am unable to form

* "The Copper-Deposits of Copper Basin, Arizona, and their Origin."—*Trans A. I. M. E.*, xvii., 479.

† "Note sur les Gisements de Cuivre du Boleo."—*Assoc. Française pour l'Avancement des Sciences*, 1885.

from the hasty description of Fuchs a clear conception as to its genesis.

The third bed lies in part below the ground-water level, and contains, in addition to the foregoing minerals, the copper sulphides chalcosine (Cu_2S) and covelline (CuS).

The ore-beds are composed of tufa (the slime, according to Fuchs, of volcanic eruptions), in which ores in disseminated spots and veinlets (*"sous forme de mouche ou de veinules"*), as well as globular concretions, are irregularly distributed, with a visible tendency to concentrate towards the bottom of the bed, where they form a compact ore-layer, 15 to 25 centimeters (6 to 10 inches) thick.

With regard to genetic questions, we must bear in mind that the ossils found in these strata indicate an open though not very deep sea; it is, therefore, impossible to assume that iron-, manganese- and copper-ores were dissolved in it, and were precipitated from it at the same time with the rock. A periodical metallic precipitation, three or four times repeated, in an open marine basin, is out of the question; and we are forced in this case, even more strongly than elsewhere, to assume a secondary origin for the ores. The data necessary for its explanation are still wanting, but can undoubtedly be secured by the further advance of mining work. E. Fuchs contented himself with pointing out the after-effects of eruptive processes, and did not enter upon the genetic question. Certainly the conglomerates underlying the ore-bed must have played an important part, representing, very likely, the channels through which the mineral solutions ascended, to be reduced, probably by the presence of organic matter, in the tufas above.

b. Metasomatic Deposits in Soluble Rocks.

A metasomatic replacement of the original rock-material was clearly proved long ago for some instances—*e.g.*, calamine-deposits—while in other cases, where proof has not been obtained, analogies in the observed circumstances speak for such an origin. Parts of such deposits, it is true, may be fillings of spaces of dissolution, rendered unrecognizable, as such, by the absence of clearly-defined crustification in the ore-precipitates. We must accustom ourselves to the fact that for many deposits, not yet closely enough studied, it is impossible to determine positively the mode of genesis, and we must often choose provisionally, of the two modes just named, the one which appears to represent better the given data.

Calamine-Deposits.—The calamine-deposits of Raibl in Carinthia,

Wiesloch in Baden, Vieille Montagne, with its vicinity, in Belgium and Germany, and other places, furnish, in the fossils of the limestone which have been transformed into calamine, the clearest proofs of a metasomatic replacement of the carbonate of lime by carbonates and silicates of zinc. Moreover, the structure and form of the ore-deposits is characteristic of this origin, these being mostly bodies of irregular outline, with portions projecting far into the country-rock. Often the progress of the replacement can be traced. Thus, at Raibl (Fig. 85), in places where the process has started from seams, the gradual advance from the seam into the rock may be observed; the outermost portions being relatively the most recent, and lying against a peculiarly uneven, rough surface of limestone.

Sometimes features of the original rock-structure are repeated in calamine, as, for instance, the cellular structure of the so-called *Rauchwacke* (the *cargneule* of the Swiss geologists), which consists of a skeleton of thin, smooth lime-partitions, from among which the limestone has been in part dissolved away, or left only in separate decomposed splinters. This is evidently the result of a very complex metamorphosis, which Groddeck has observed also in the quicksilver-deposit of Avala in Servia. The cell-walls, which represent the fillings of cracks in a shattered limestone, have been *sub*sequently changed to calamine, and covered with botryoidal clusters of that mineral (Fig. 86).

Calamine is frequently formed by atmospheric agencies above the ground-water level, and is a frequent accompaniment of lead- and zinc-deposits in limestone.

Space does not permit the description here of the manifold deposits in Belgium, Rhenish Prussia, Westphalia, Upper Silesia, Sardinia, Algiers, etc., which are, moreover, not known to me by personal observation. The text-books of Cotta, Groddeck and Phillips give some account of them, and refer to sources of more detailed information.

Laurium.—It is only in recent periods that the features of the extensive mining region of Laurium in Greece,* worked two thousand years ago, have been described. Although various kinds of deposits are represented, most of them belong under the present head.

In the Camaresa district, a series of nearly horizontal, non-

* A. Cordella, *La Grèce sous le Rapport Géologique et Minéralogique*, Paris, 1878; and *Le Laurium*, Marseilles, 1869. A. Huot, *Rapport sur les Mines du Sunium*, 1880, and *Mémoires de la Société des Ing. Civ.*, 1876–78.

fossiliferous limestones and crystalline schists is cut by a number of eruptive dikes, and suddenly assumes on the NE. a steep dip, probably indicating a considerable dislocation. The whole group is traversed by a number of ore-veins, which, in the schists, are often rich enough to pay for mining. But the main mass of the ores lies on the contact between limestone and schist, and extends into the former in separate bodies or shoots. At the so-called second and third contacts, the bodies have a prevailing funnel-shape and a vertical position. Fig. 87, an illustration from Huot, shows the apexes of the funnels to point on one contact upward, and on the other downward—but, in either case, into the limestone, according as it overlies or underlies the schist. The first form may be explained by the pressure of the ascending solutions. The second, as shown in this figure, is perhaps somewhat ideally sketched; at least the sections of this third contact given by Cordella show ore-bodies following the contact-plane itself.

According to Fig. 88 (also from Huot) the ore-bodies are funnel-shaped in N. to S. section, but from E. to W. have a flat westward pitch, which is hard to explain unless it represents some kinds of cleavage parallel to the dislocation already mentioned. Below the second contact, which carries chiefly lead, there are (at the Jean Baptiste shaft, for instance, according to Cordella) great masses of calamine, the secondary origin of which from zinc-blende is doubtful, since it would involve the assumption that the ground-water zone had extended to this depth. As to the present subterranean water-level, I find in the descriptions at hand only the statement that the region generally is very dry, and that the ancients, who mined to the depth of 120 meters (394 feet) had no water to hoist. With regard to the structure of the galena-deposits, I may say that I saw in the exhibit of the *Cie. Française des Mines du Laurium*, at the Paris Exposition of 1867, masses of galena, blende and pyrite showing distinct stratification, but did not learn from which deposit they came.

Which of the various eruptive rocks of the district (eurite, porphyry, diabase, serpentine, trachyte) gave occasion for the ascending springs which brought up the ore, cannot as yet be determined.

The minerals accompanying the products of decomposition in such deposits, particularly of calamine, are naturally often limonite and other ores of iron. In many countries these play an independent part, being often formed by the metasomasis of limestone, as proved by the irregular masses of the deposits and the contained fossils transformed into ore.

Alsace.—An instance is furnished by the so-called *Bohneisenerze* of Alsace and adjacent regions which have been described and correctly explained by Daubrée.*

At Liebfrauenberg, irregular, lean beds of this character, composed principally of limonite, but scarcely workable with profit, lie on both sides of an anticlinal of Vosges sandstone, and are covered with alluvium. In one place, however, near Goersdorf, an undecomposed body of pyrite and mispickel occurs instead of limonite.

Cumberland.—In Cumberland, limonite-deposits occur on the contacts of the Carboniferous Mountain limestone, both with the overlying millstone grit and with the underlying Silurian schists. They are connected with fault-fissures, on both sides of which they appear, as is shown in Fig. 89, taken from a paper by Mr. J. D. Kendall.†

Carniola.—The Alps offer some remarkable examples of *Bohneisenerze.* These occur, according to A. von Morlot,‡ in the region of Wochein in Carniola (known for its iron-ores and bauxite) in the dolomite and limestone mountains only, and either in the form of beds under the dolomite detritus, or in clay, in the caverns of the dolomite. Fig. 90 is a section showing the latter form. In this case the flatter-lying cavern was partly filled with lime-detritus and clay up to its connection with a higher vertical cavern, while the latter was filled with *Bohnerze* enclosed in loam, and had been mined, according to Morlot, to the considerable depth of 250 meters (820 feet). Here and there a nucleus of pyrite is found in the iron-ore. The beds and mass-deposits of bauxite associated with limonite sometimes show also the "bean-structure."

c. Deposits in Crystalline Schists and Eruptive Rocks.

Without entering here upon a discussion of the subject of regional metamorphosis, I may remark that, as a general rule, the older a rock is, the more changes it will be found to have undergone; yet that these changes do not advance in all places uniformly. Many Cretaceous and Tertiary formations of the Alps present a highly metamorphosed, and therefore ancient, appearance; while many Silurian formations—as, for instance, that which surrounds St. Petersburg—

* *Les Eaux Souterraines aux Époques Anciennes*, p 89.

† *Trans. N. of E. Inst. of M. E.*, 1878, vol. xxviii., pl. xxviii.

‡ "Geol. Verhältn. von Ober-Krain," *Jahrb. d. k. k. Geol. Reichsanst.*, i., 1850, p. 407.

have been so little altered that the fossil shells which they contain still have the mother-of-pearl luster. Some regions, in a word, have been more strongly attacked than others, through causes which we will not here pause to consider; and when we follow the stratified groups downward, we come upon the various crystalline schists often traversed by eruptives, and showing no longer any trace of the clastic sediments, which have been wholly transformed to crystalline masses. We cannot hope to find petrified organisms in these masses; but the occurrence of disorganized organic material in the form of anthracite and graphite proves that at the time the rocks were formed, organic life must have been represented in the sediments.

Many indications, available in the distinctly sedimentary rocks as guides in the determination of the relative age of their ore-deposits, are here wanting. The bedding becomes more and more obscure, and is sometimes no longer distinguishable from the cleavage. Many of the ore-deposits in these rocks have also become in whole or part crystalline, adjusting themselves to the prevailing stratification or cleavage, so that most of them present a bed-like structure and form. Whoever believes in the possibility of a contemporaneous formation of the ores with the rocks will not trouble himself here with genetic speculations, but will see in these deposits simply "ore-beds," according to the old classifications.

Taberg, Sweden.—The circumstance that magnetite is a constituent of many eruptive rocks has inclined many geologists to regard masses of magnetite in the neighborhood of such rocks as immediately belonging to them. This theory originated in connection with the Taberg deposit, in Småland, Sweden, and was propagated by F. L. Haussmann,* W. Hissinger,† and A. Daubrée;‡ and Taberg has been regarded ever since as an example of the primitive existence of magnetite-deposits, those of Kackanar, Visokaya Gora, and Blagodat being classed with it.

The question arises, where the line is to be drawn between an eruptive rock containing magnetite and a magnetite deposit. An eruptive rock, like that of Samokov, in the Pils mountains in Bulgaria, from the weathered detritus of which magnetite is obtained by ore-dressing, is not properly an ore-deposit; but, on the other hand, that of Taberg, where the ore is not only finely disseminated

* *Reise durch Skandinavien*, Göttingen, 1811–18, i., p. 165.

† *Versuch einer mineralog. Geographie von Schweden* (Woehler's translation), 1826, p. 205.

‡ *Scandinaviens Erzlagerstätten* (edited by G. Leonhard), Stuttgart, 1846, p. 25.

in large amount, but also occurs in separate, solid veins, may fairly be so called. According to A. Sjögren,* the rock consists of olivine, magnetite, and a little plagioclase, with mica and apatite as accessories. In other words, it is an already metamorphosed rock. Considering that at several places in Scandinavia magnetite occurs in the crystalline schists also, it seems unlikely that the magnetite of Taberg belongs to the primitive rock. This is confirmed by the observation of Th. Kjerulf, that all the ore-deposits of Norway follow the courses of eruptive rocks. Taberg will scarcely prove to be an exception, and may, therefore, be regarded as a secondary or xenogenous ore-deposit.

Before proceeding further I must mention the action of the mineral solutions upon the country-rock of some veins, which might be also classed as impregnation. In this respect tin-deposits are most interesting, because they carry ore, not only in the space of discission, *i.e.*, the vein-fissure, but to a large extent in the neighboring country-rock also. If the veins occur in granite, this is changed for a certain width into greisen, *i.e.*, it is robbed of its feldspar, which is even, in some cases, replaced by cassiterite and associated minerals. Thus are formed the beautiful pseudomorphs of cassiterite after feldspar, which adorn many mineral collections. (See Fig. 91.)

Figs. 91–93 are taken from C. Le Neve Foster.† Fig. 91 represents the alteration of the granitic country-rock to greisen on both sides of a fissure, which is here filled with symmetrical quartz-crusts, to the central druse or comb. Often such fissures occur close together; and since each has its own zone of greisen, the result is a *Stockwerk*, constituting a metamorphosis of the granite, and formed by these fissures.

Cornwall.—In the slate or *killas* of the Cornish miners, there is often a disturbance of the bedding in the neighborhood of the fissure (Fig. 92), such as is observed in connection with fault-fissures elsewhere; but in this case the *capel*, or adjacent portion of the slate, is altered chemically also, being impregnated with quartz and traversed by streaks of ore. The fissure itself is filled with quartz, cassiterite, chlorite, pyrite, and fragments of the *capel*. When several fissures come together, the result is somewhat complicated, but can be reduced to the simple case just described.

* *Neues Jahrb. f. Mineralogie*, 1876, p. 434.

† "Remarks on Some Tin-Lodes in the St. Agnes District," *Trans. Roy. Geol. Soc. of Cornwall*, 1877, ix., Pl. III.

Still more interesting is the tin-deposit of East Wheal Lovell, described by the same authority.* At the side of a narrow quartz vein the ores occur in the granite, from which they are not separated by any definite boundary, so that the ore-body is an almost vertical shoot, confined to the neighborhood of the fissure, yet lying in the country-rock. It is clear that a mineral water of high solvent power, must have ascended under great pressure, in order to bring about such effects in a rock ordinarily regarded as insoluble. Fig. 93 shows the situation of one of these ore-shoots in granite, at the East Wheal Lovell mine.

The ore-deposits in metamorphous and eruptive rocks occur especially in the great crystalline northern areas, in Scandinavia, Canada, and the northeastern United States.

Scandinavia.—In Scandinavia, the science of ore-deposits, like that of petrography, has had a comparatively independent development. Although these countries have been often visited by foreign observers, few analogies with European deposits have been noted—chiefly, no doubt, because of the peculiar character of the occurrences examined, but also partly because of the differing standpoints and views of native observers. In recent times a difference of interpretation has developed itself between the Norwegian and the Swedish geologists; and the former, since Kjerulf, have approached more nearly the Continental view.

As already remarked, Kjerulf traces all the ore-deposits of Norway to the filling of spaces of discission, and particularly of a peculiar space, produced by the sliding of the rock along a bedding-plane, and locally called a *Lineal.*

With respect to the ore-filling, he points out that the occurrence of the ore-deposits must always be studied on the large scale, and that this method shows the ore-deposits to occupy certain lines, characterized by the presence of eruptive rocks.† The ores appear chiefly in the crystalline schists, but also in traces along the contact, and sometimes in the eruptive rocks themselves. In the first case, the different sulphides, mostly accompanied with quartz, lie parallel with the bedding or cleavage of the rock, and thus look like beds; but their secondary origin is indicated by the slickensides, the branching of the deposits and other signs. Sometimes it is made evident

* C. Le Neve Foster, "Remarks upon the Tin-Deposits of East Wheal Lovell," *Trans. Roy. Geol. Soc. of Cornwall*, 1876, ix., Pl. II.

† *Die Geologie des südl. u. mittl. Norwegen* (authorized German edition, by Dr. A. Gurlt), Bonn, 1880, pp. 81, 284, 293.

by the course of the ore-masses, cutting across the bedding or cleavage. In the museum at Christiania there are many large specimens of the ore, some of which, having been polished, show this structure plainly. Pictures of some of them have also been published by Kjerulf.*

In this connection, the primitive ore-bearing character of the *Fahlbänder* (so often cited by geologists as primary ore-beds, which enrich the veins by which they are crossed) is entirely denied (*l. c.*, p. 323). It has been proved that the ores of the Modum fahlbands are connected with the malacolite and the augite-rock which intrudes in "lineal" form between the steep strata of quartz-schists. Figs. 94 and 95 are intended to show the appearance of these deposits, formerly deemed to be beds. The former represents a specimen from the Kongens mine at Röras, and the latter a part of the specimen illustrated by Kjerulf, from the Mug mine at Trondhjem. In the former, the subsequent entrance of the ore is at once recognized. The latter appears as if the crystallization of the minerals had taken place after the ore-impregnation.

Of course, the political boundary does not divide the nature of the ore-deposits of the Scandinavian kingdoms. Those of Sweden are often the continuations of the Norwegian. The crystalline rocks are here peculiarly developed, and have also been peculiarly named by the Swedish petrographers. In the Swedish granulite, for instance, one would scarcely recognize its Continental namesake. These rocks are not in general so coarsely crystalline that their constituent minerals can be distinguished with the naked eye. The so-called eurites are still finely crystalline, and the *hälleflinta* is almost amorphous, consisting only of the ground-mass of the massive rocks. The beds and mass-deposits of the crystalline rocks are often, like many of the Norwegian deposits, associated with talcose and chloritic slates. Sometimes limestone is also present, as at Falun, Tunaberg, etc., where the ores lie on the limestone contacts. The ores of some of the deposits suffer in depth a remarkable change. Thus the mass of copper pyrites at Falun has diminished in depth; but, on the other hand, gold-bearing quartz-veins appear in the midst of the pyritic body, and have yielded in recent years considerable amounts of gold.

Åmmeberg.—I will cite as an example one of the most interesting

* "Pragstufer med Braeciestruktur fra Muggruben og Stovarts," *Magazin for Naturvidens, Kobern*, xxvii., B., p. 335.

deposits, namely, the zinc-blende mine of Åmmeberg,* belonging to the Vieille Montagne Company, which I have personally examined.

In a winding line, chiefly E.–W., and about 3½ kilom. (2 m.) in length, occur steeply-dipping beds of zinc-blende in granulite, or gneiss resembling granulite. At certain points they show very beautiful, close folds. At first glance they seem to be genuine intercalated beds of the same age as the rock. The ores, however, do not continue along the whole line, but form separate lenses, up to 15 meters (49 feet) thick, which show a distinct stratification, consisting in layers of fine-grained to amorphous material resembling *hälleflinta*, alternating with the coarser granulite. Fig. 96 is a polished specimen, which exhibits clearly the secondary ore-invasion. The original bedding is here indicated by a series of light and dark dense *hälleflinta* layers; and these are broken through by masses of coarsely crystalline rock and of ore. The entrance of the ore into the coarsely crystalline layers seems to have been attended by an enlargement of their volume, which resulted in their breaking through the dense layers.

The same explanation is required for some parts of the bed, in which, between the plane surfaces of two fine-grained, barren strata, ore occurs in highly folded and contorted layers. This folding is due by no means to an exterior mechanical energy, but to interior chemical forces.

Some of the blende layers carry a considerable admixture of galena, as, for instance, the two ore-layers shown in Fig. 97, separated by a fine-grained, yellow to brown, barren stratum of eurite. The whole mass is traversed by fine fissures perpendicular to the bedding, which are filled with leaf-silver, looking like tin-foil. A replacement with ore of the original rock-constituents is here beyond question.

It is supposed that the blende has taken the place of the mica of the granulite. But the whole country-rock also is metamorphous. At the open cut of the Godegärd II. mine-working I found in the midst of the schists what I took to be limestone, but I subsequently lost on my journey the specimens intended for more careful examination. But petrographers have probably long since determined this point.

This Åmmeberg deposit, then, although so distinctly bedded, is by no means of primitive origin; and still less can such an origin be supposed for the others, which occur as lenses of the greatest variety

* A Sjögren, "Undersökning of den omgrifande Bergarten on Åmmebergs Gruf-vor." *Geol. Föreningens i Stockholm Förhandl.*, 1880, V.

of filling, enclosed in the crystalline schists. If mica may be replaced with zinc-blende, magnetite, etc., such a change will, of course, be confined to certain portions of the rock, immediately within range of its cause; and these portions, as distinguished from the rest of the country-rock, are to be considered mineral deposits.

Some of the ore-deposits of the Alps have a certain similarity to those of Scandinavia, for instance, Prettau, in the Ahrn valley, in Tyrol; Brennthal, near Mühlbach, in Salzburg; and Schneeberg, near Sterzing, in Tyrol.

Prettau in Tyrol.—There is here a very ancient copper-mining industry, which was overwhelmed in 1878 by a great disaster, and will not soon recover; namely, the settlement at the smelting-works was buried by an avalanche so deep in débris that it has been necessary to sink shafts nearly 20 meters (65 feet) deep and mine out the stock of manufactured copper and other objects of value.

The crystalline schists, which here strike E. and W., and dip steeply S., contain impregnations of copper and iron pyrites, very short horizontally, but considerably prolonged on the dip. The deposit has been opened to a vertical depth of 500 meters (1640 feet), representing 600 meters (1968 feet), so that the horizontal projection, or distance between the top and bottom is only 350 meters (1148 feet). Figs. 56 and 57 are a vertical section and plan. Figs. 54 and 55 are sketches from the roof and side of the Ottilie gallery, where the chlorite-slate and pyrites present highly complicated forms, somewhat like the structure I have observed in the Transylvania rock-salt. It may be explained, in my opinion, either by an interior increase of volume or by a distortion of the chlorite-slate in the steep westward-pitching line indicated by the ore-deposit. It is extremely difficult to form a correct conception of this deposit. I was able to study some of the lower levels only.

It is remarkable that the pyrites-mine of Brennthal, near Mühlbach, shows an entirely similar structure and form of ore-bodies, and almost the same westward pitch upon the E.–W. plane of the stratification. It looks as if dynamic movements connected with the mountain had played a leading part in thus determining the same pitch for the ore-bodies of deposits on opposite sides of the Central Alps.

Where the ore-body begins to grow poor, and the pyrites appear disseminated in grains and crystals through the chlorite, the secondary character of the impregnation is clearly recognizable. The space for the massive ore-body was probably prepared by mechanical

forces. That a metamorphosis was the cause is not likely, because the original minerals of the stratified group could scarcely have assumed such abnormal form and dimensions.

The older rocks occupy in America large areas; and there also many ore-deposits occur and are worked which, although somewhat unlike those of Scandinavia, belong to a similar type. I do not intend to describe here the numerous and well-known ore-deposits of the Eastern and Northern States; but I cannot avoid brief mention of some peculiar types.

Lake Superior.—The copper-district of Lake Superior offers a number of very interesting occurrences, some of which, though developed by extensive mining, and often described at considerable length, have not yet been satisfactorily explained. It is remarkable that copper and silver occur here almost exclusively native; but it is very generally admitted that this is not the usual primitive form of copper. Sulphides seem to occur but seldom, and they receive, as a rule, no attention. I saw once, at Lac-la-Belle, an old working upon pyrite, chalcocite and galena, which was said to have carried some native copper in its upper levels. But Foster and Whitney do not mention it.*

The native copper of this district occurs notoriously in both veins and beds, in a stratified group lying between the Huronian and the Cambrian, and traversed by numerous flows of eruptive rocks.† We are here concerned with the beds. The ore in the Calumet and Hecla mine is a conglomerate of porphyry pebbles; another, in the Copper Falls mine, is a dark lava-flow, the so-called "ash-bed." The latter is impregnated with copper on both sides of the Owl Creek vein, which traverses it (Fig. 98); while in the Calumet and Hecla conglomerate, copper sometimes constitutes the cementing material.

In both masses the spaces now filled with copper were unquestionably once filled with other substances; and the present conditions are the result of whole series of complicated replacements.

R. Pumpelly, who originally believed in a contemporaneous ori-

* *Report on the Geology and Topography of a Portion of the Lake Superior Land-District*, i., Washington, 1850, p. 139.

† M. E. Wadsworth, "Notes on the Geology of the Iron and Copper-Dist. of L. Superior," *Bull. of Mus. of Comp. Zool.*, Harvard College, Cambridge, vii., 1880.

R. Pumpelly, "The Paragenesis and Derivation of Copper and its Associates on Lake Superior," *Am. Jour. Sci.*, 1871, cii., pp. 188, 243, 347.

R. Duer Irving, "The Copper-bearing Rocks of L. Superior," *U. S. Geol. Sur.*, 3d *Ann. Rep.*, Washington, 1883, p. 89.

gin of the copper and the enclosing rock, became subsequently convinced that the copper had replaced especially epidote and chlorite, and that certain phases of metasomatic processes were here represented. The eruptive rocks have usually been strongly attacked—for instance, the pebbles of the conglomerate, the rocks on Isle Royale, etc. Some portions, on the other hand, *e.g.*, the Ash-bed, have been little attacked. The former instance (which the latter, it is true, contradicts) was used, long before Sandberger, as proof of a sort of lateral-secretion theory; and now and then, where the copper-bearing rock was overlain by an eruptive flow, the theory of descending solutions was also brought into play.

Some of the attempted explanations assume, in my opinion correctly, as the cause of the first ore-depositions, the action of hot springs—in which connection it is only to be emphasized that these thermal effects occurred long after the intrusion of the eruptive flows between the sedimentary strata, so that the ores were brought, not by or in the eruptives themselves, but by the later springs, from great depths and perhaps from considerable distances. This explanation, applicable to all the deposits, suits also the exceptional case cited by R. D. Irving, namely, the Nonesuch copper-bed in the sandstone of Porcupine Mountain, far from an eruptive outflow.

As to the condition in which the ores were first deposited, and the manner in which they became reduced and associated with zeolites, additional data must be sought for the formation of an opinion.

Sudbury, Canada.—Quite recently, A. B. von Foullon has published his observations in the Sudbury region, Canada,* expressing certain theoretical conclusions of great interest, which, however, flatly contradicted my view. They concern the pyritic deposits which occur in Huronian rocks, but at the borders of eruptive outflows of diorite, etc., and were described by T. G. Bonney† and afterward by R. Bell.‡ The ores are associated with masses of diorite, intercalated conformably in the stratified rocks. The ore-bodies have the form of "stockworks," and consist of an irregular mixture of rock and metallic sulphides (?). In the ore, which contains gold, platinum, tin, lead, silver, zinc and iron, occur also feldspar, quartz and apatite. This account, taken from Bell's description, indicates a strong analogy with the Scandinavian deposits.

* "Ueber einige Nickelerzvorkommen," *Jahrb. d. k. k. R. A.*, xliii., 1892, p. 276.

† "Notes on a Part of the Huronian Series in the Neighborhood of Sudbury," *Quart. Jour., Geol. Soc. of London*, xliv, 1888, p. 32.

‡ "The Nickel- and Copper-Deposits of Sudbury District," *Bull. Geol. Soc. of Am.*, ii., p. 125, Rochester, 1891.

Foullon, who made in this field a series of highly valuable observations, supported by careful chemical analyses, expresses himself finally concerning the genesis of these deposits, as follows:

"The irregular mixture of pyrites and silicates, presenting copper pyrites and magnetic pyrites enclosed in the rock in the most varied quantities and in all conceivable forms; and, furthermore, the circumstance that sometimes the ore occurs disseminated in the diorite, and sometimes the diorite is enclosed in the ore, now the rock, and again the pyrites, being the ground-mass, prove unmistakably their contemporaneous origin. At certain periods of the diorite eruption, the magma was rich in accessory constituents which rendered possible the formation of the metallic sulphides; and these were segregated during solidification."

R. Bell has expressed himself still more plainly.

The ores are not of humid, but of molten origin, as is proved by their occurrence in the diorite, with which they ascended. The masses of molten diorite must have remained long liquid, so that the metallic sulphides could separate, become concentrated at certain points, and continue with the fragments of diorite. Large quantities of the molten diorite, and the heavy metals, must have retired again.

These surprising statements assume a chemical impossibility, namely, the presence of metallic sulphides in the magma of the molten eruptive rock, after the fashion conceived by H. C. von Leonhard,* on the strength of metallurgical analogies.

Shaft-furnaces, operated for a separation of the ingredients of the charge, produce slag, metallic sulphides (matte) and reguline metal. But the above hypothesis involves rather a common fusion of all, and a separation *in cooling* of slag (diorite) and matte (metallic sulphides). These authors should certainly not omit to explain further the principles upon which their explanation is based, taking into consideration at the same time the inner structure and other relations of the deposits in question, such as their conformity with the stratified rocks of the region; the occurrence of ore-channels, quite similar to those encountered in deposits formed by aqueous circulation, etc.

These pyritic deposits contain almost all the heavy metals, including platinum and gold, and it is remarkable that the latter here occurs in quartz, exactly as it does generally, throughout the world.

The untenable character of the explanations above quoted must be evident, and this brief mention of them will be sufficient. Yet it appears that there are other inquirers into the genesis of ore-deposits who purpose to take a similar standpoint.†

* *Hüttenerzeugnisse und andere auf künstlichem Wege gebildete Mineralien als Stützpunkte geologischer Hypothesen*, Stuttgart, 1858.

† For instance, J. H. L. Vogt, of Christiania, "Bildung von Erzlagerstätten

4. Hysteromorphous Deposits.

Under this title are included the deposits formed by the chemical and mechanical influences of the surface-region, from the original deposits of which the conditions of origin have been considered above. These formations have been considered and named from various standpoints. Thus the name "deposits of débris" emphasizes the idea of a mechanical crushing or disintegration; the German term *Seife*, like the Spanish and American "placer," is based upon the manner in which such deposits are often mined for their metallic contents, and so on. The expression "secondary deposits" satisfies, it is true, the definition given above, but is rendered ambiguous by its frequent use in other meanings connected with the genesis of ores. I feel warranted, therefore, in proposing for this group the more distinctly significant name "hysteromorphous" (later-formed).

The influences of the present surface upon deposits found in the deep region are so characteristic as to permit us to draw conclusions concerning the processes of earlier periods, when the surface occupied a very different position. Unquestionably, effects similar to those of to-day were produced then also, and we must include in our consideration of the subject the hysteromorphism of former geological periods.

a. Chemical Effects.

The chemical effects proceeding from the present surface have been already discussed in many respects. They involve not only phenomena on the surface itself, but extend beneath it to the ground-water level, and even below that level, so far as the vadose circulation is traceable.

On the surface it is especially the oxidizing effect of the atmosphere, its contained carbonic acid, and the solvent and chloridizing action of atmospheric precipitation, simultaneously aided by the mechanical effects of wind and moving water, which bring about what Justus Roth* has called "simple weathering," to distinguish it from more complicated forms of decomposition. In considering not merely rocks, but outcrops of complex ore-deposits, we encounter what Roth calls "complicated weathering."

Decomposition underground, through the action of the same

durch Differentiationsprocesse in basischen Eruptivmagmata."—*Zeitsch. f. prakt. Geol.*, 1893, i., p. 4.

* *Allgem. u. Chem. Geologie*, vol. i., Berlin, 1879, pp. 69–158.

atmospheric constituents of the surface-water, extends, as is well-known, to the ground-water level, where it may manifest itself in a striking way by reason of the frequent occurrence at that level of the alternation of dryness with moisture, which is a factor greatly promoting decomposition.

A similar condition is presented, as was pointed out in Part I., by the workings of mines, where the water-level has been artificially lowered, and a zone of depth previously untouched by the vadose circulation is brought within the domain of that agency. Deep and old metal-mines especially exhibit in a striking way the effects of the vadose circulation, and, in addition, a phenomenon but seldom found in places under the influence of the natural water-level, namely, the effect of the mine-waters upon various surface relations and products.

Limonite-Deposit near Rio Tinto, Spain.—One of these rare instances is cited by J. A. Phillips* in his group, "Deposits resulting from chemical action." Namely, in the vicinity of the great iron and copper pyrites-deposits of Rio Tinto, in Spain, there occurs a deposit of hydrated ferric oxide, shown by the fossils it contains (which correspond with species still living in the region) to be of recent origin, and undoubtedly produced by the weathering and decomposition of the neighboring pyritic deposit. It was deposited in a swamp-like basin with peaty matter, and subsequent erosion has left of it two remnants only, at Mesa de los Pinos and Cerro de las Vacas respectively. Evidently, in this case, the detritus of the pyritic deposit has not been mechanically swept away and collected elsewhere, but a chemical action has taken place, removing material in solution, exactly as in the formation of bog iron-ores. The formation here is certainly earlier than the Roman period, for Roman tombstones have been found, made of this recent iron-ore.

Mine-waters contain the solutions of all substances directly or indirectly dissolved by the vadose circulation, and some of these, encountering suitable precipitants, may be thrown down. Thus, ferrous oxide becomes by oxidation hydrated ferric oxide; many metallic sulphates are reduced by organic matter to sulphides; copper-salts may even be thus reduced to metal, etc. These new precipitates will mark the track of the mine-waters.

Finally, while the solutions formed by surface-waters, like those of the mine-waters, mostly find their way to the points where the

* *A Treatise on Ore-Deposits*, London, 1884, p. 15.

water-level reaches the surface (drainage-points), yet as a part of the ground-water penetrates to greater depths, such solutions may very likely produce, in the deep region itself, impregnations, which must, however, differ in character from those produced by the deep circulation proper.

The primitive deposit from which such solutions have come will show remaining in it principally substances not easily soluble, together with such as, like precious stones, resist all atmospheric influences. Meteoric waters, carrying oxygen, some carbonic acid, and small quantities of chlorides, will first oxidize whatever is oxidizable, especially the metallic sulphides. On this subject S. H. Emmens* has published a clear statement, with some practical deductions. He distinguishes in the order of liability to decomposition the following degrees: (1) marcasite, (2) pyrite, (3) pyrrhotite, (4) chalcopyrite, (5) bornite, (6) folgerite, (7) millerite, (8) chalcocite, (9) galena, and (10) zinc-blende. The acid ferric sulphate formed from the first members of this series immediately attacks the latter members. The carbonic acid contained in the circulating waters has a high solvent power, and, among other things, dissolves the carbonate of lime as a bicarbonate, which reacts upon the basic sulphates, producing gypsum and free carbonic acid, and ultimately transforming lead sulphate into carbonate (cerussite). Copper oxide and, under some circumstances, native copper, may be formed from copper sulphate, and so on.

For the chlorine of the chlorides, lead and silver have the strongest affinity, and these metals will consequently be often found in the upper zone as chlorides.

The decomposition above water-level of gold- and silver-bearing deposits facilitates the extraction of these metals. Metallic gold can be extracted by simple processes of mechanical concentration and amalgamation from oxidized material, while gold in undecomposed sulphides, etc., must be roasted, smelted, or chlorinated with more or less cost and difficulty. Silver likewise occurs, as a rule, in this upper decomposed zone in the form of easily amalgamated combinations (free-milling ores), while the refractory ores of deeper zones are much harder to treat.

It is doubtless for these reasons that mining enterprises often come into very critical conditions when they reach water level, and many mines even cease to be profitable. An important part, no doubt, is

* "The Chemistry of Gossan," *E. and M. J.*, 1892, liv., p. 582.

played by other causes, such as the necessity of hoisting increased quantities of water, the cost of the required machinery, etc.

It is remarkable that in western North America the ground-water level lies deeper than is generally the case in Europe. I suppose the reason to be, that the present area of the Interior Basin of North America, which has no surface-drainage to the ocean, was formerly cut by deep valleys of erosion, which made a deeper escape of the ground-water possible. This suggestion is confirmed by the level valleys of Utah and Nevada, several miles wide and filled with very recent sediments, between comparatively narrow mountain ranges, which seem to be, so to speak, the tops only of the former ranges.

In Europe, the upper zones of the ore-deposits were worked out long ago, at a time when the science of chemistry was in its infancy. But we know from the remnants in these workings that chlorides, lead and silver carbonates, and various sulphates, such as anglesite, occurred in them, though they were not recognized. In Transylvania the decomposed products of the outcrop-zone were called *Bräunen* ("browns"), with evident reference to the brown hydrated ferric oxide. The well-known maxim of the German miners concerning the "iron hat" is very ancient; and the same may be said of the Cornish proverb, "Gossan rides a high horse." Limonite is certainly a characteristic indication of the outcrop of an ore-deposit; and no doubt its reddish-brown color has chiefly suggested the South American miners' names, *pacos* and *colorados*.

In a few instances the "iron hat" has been actually mined as an iron-ore. As a rule, it is the decomposed, porous and honey-combed vein-material of the upper zone, and is colored only with limonite. The part of the ore-deposit above water-level has a characteristic appearance. Quartz and other refractory gangue-minerals are surrounded and impregnated by earthy limonite masses. As a rule the original texture of the deposit has become obscure; and sometimes fragments of the mineral crusts, broken off and crushed through changes of volume, are found chaotically thrown together. Occasionally, however, the original structure may still be traced in the decomposition-products of the several crusts, unaltered nuclei of the ore being discoverable in them. Some substances (especially calamine formed from zinc-blende) display the stalactitic forms characteristic of the vadose region. Original druses as well as recently formed cavities are filled with new material; and in this way a secondary crustification may occur.

I must not forget to mention that there are some observations

according to which gold has been precipitated chemically in hystero-morphous deposits. Oscar Lieber,* F. A. Genth and A. R. C. Selwyn expressed the opinion that detrital gold generally, or a portion of it, has been deposited from solutions. Laur, J. A. Phillips, Wilkinson, Newberry, Daintree,** Skey, Egleston,† etc., have accepted this view as more or less generally applicable. E. Cohen‡ has undertaken to examine it critically, and is inclined by his own experience in South Africa "to adopt the conclusion reached by Devereux for the Black Hills of Dakota, and to assume that by far the largest part of the detrital gold has been liberated by the mechanical destruction of older deposits and has been mechanically laid down; while, on the other hand, a precipitation from solutions undoubtedly takes place, but plays a very subordinate part only."

My own opinion on the subject is expressed in the above quotation.§ No doubt here and there, in the detrital deposits, traces of chemical activity are discoverable; but they are not sufficient to weaken the evident proofs of the mechanical origin of detrital gold.

b. Mechanical Effects.

The mechanical effects of moving air and water, of frost and ice, are grouped under the head of erosion, and are treated at length, so far as rocks in general are concerned, in the geological text-books. We are here concerned especially with effects of this kind produced upon those portions of ore-deposits which are exposed at the surface. We notice at once that mechanical, unlike chemical effects, are confined to the surface or a very small distance below it. In general, we must assume that the chemical changes took place first, but that the progress of erosion brings both to our view at the same time.

Verchoviky, or Surface-Deposits in Situ.—Not only water and ice (glaciers), but also wind, takes part in erosion. For instance, if an ore-deposit, by reason of its greater resistance, crops out above the level of the country, the wind will continually tend to blow away the finer and lighter portions of the detritus formed by chemical

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* In Cotta's *Gangstudien*, and in *Geol. Rep. of S. Carolina*, 1860.

** See A. G. Lock's *Gold, its Occurrence and Extraction*, pp. 754–8, 814.

† "The Formation of Gold Nuggets and Placer-Deposits," *Trans. A. I. M. E.*, ix., 1881, p. 633.

‡ "Ueber die Entstehung des Seifengoldes," *Mitth. d. Naturw. Vereins f. Neupommern u. Rügen*, xix., 1887.

§ See my article, "Zur Genesis der Metallseifen," *Oesterr. Zeitsch. f. B.-u. H. wesen*, 1887, xxxv., p. 325.

processes of weathering; so that, in the course of time, there must remain of the original outcrop only the heavier portions, so far as these are not carried away by water. In fact, I have observed in the Urals that the gold-diggings of the valley, undoubtedly formed by water, extended up the slopes to points where this could not have been their origin. The gold-bearing weathering-detritus is then called *Nagornyje rozsypy* and *Verchoviky*.

A similar feature was observed by W. C. Kerr* in the auriferous deposits of North Carolina; and I have seen it in the old gold-workings of Bergreichenstein and Nesvacil, in Bohemia,† where flat mountain ridges are covered with old pits and dumps. It is impossible to consider them as diluvial terraces, for the alluvium passes over, so to say, into the solid gneissic rock, which is traversed by many quartz veins. The gold occurs concentrated in the deepest portion of the weather-detritus, that is to say on the contact with bed-rock, and has penetrated all the open, loosely-filled fissures in the latter.

Cotta‡ speaks also of deposits of débris in place, which occur on high plateaus and mountain slopes, and consist of products of weathering which are not rounded pebbles or sand and slime, accumulated by water-currents. A. G. Lock§ speaks of surface-deposits being "a result of the disintegration of the rocks *in situ*," and says:

> "The gold it contains is quite angular, hackly, or crystalline, and is derived from auriferous quartz reefs or leaders, existing in the immediate vicinity."

Similar conditions obtain very significantly in the Kackar district, to be hereinafter more fully described.

Theory of the Sinking of Heavier Constituents.—But the great agent in the transportation and re-deposition of the metallic portions of original deposits has unquestionably been flowing water; and this is an equal factor in the removal of the rock-detritus of erosion, which it is constantly striving to carry to the ocean. River-sediments are notoriously unstable. What is deposited this year is carried further down stream in the years next following, and so on until it comes to comparative rest in the sea. The

* "Some Peculiarities in the Occurrence of Gold in North Carolina," *Trans. A. I. M. E.*, x., 475.

† "Zur Genesis der Metallseifen," *Oesterr. Z. f. B.-u. H.-wesen*, 1887, xxxv., p. 325.

‡ *Erzlagerstätten*, i., Freiberg, 1859, p. 100.

§ *Gold, its Occurrence*, etc., London, 1882, p. 828.

original deposits, furnishing the material thus transported over great distances and areas by water, are well called by the Russians *Korennyje mestorozdenyje*, or root-like deposits,—that is, as it were, the roots of the scattered hysteromorphous deposits.

The attempt has been made to explain the concentration, especially of heavy metals, like gold and platinum, in certain paying layers of the detritus, by a sort of natural concentration process. The circumstance that the richest gold-deposits most frequently lie in the lowest stratum of the detritus, immediately on the bed-rock, yet that several such horizons occur one over the other, is difficult to explain in this way; for Cotta's assumed separate periods of formation (*op. cit.* i. p. 102) are scarcely satisfactory, involving as they do either periodic transportation or periodic deposition, neither of which is probable.

I believe that I have found in the Ural gold-placers a much more probable explanation, based on the principle that the specifically heavier elements of a loose mass are able, with the aid of water, to work their way down through the lighter portions. At the Przibram concentrating-works, it is found that if the pulp is left standing for a considerable period, the galena will accumulate at the bottom. In gold- and platinum-concentrating establishments, it may be often observed that these heavy metals find their way into the floor and woodwork of the mill, from out of which they are from time to time recovered by working up these materials. Why should this happen in artificial operations only, and not also under natural conditions, where the descent of the heavier portions is essentially aided by the percolation of atmospheric waters through the loose covering-material?

This view is supported by the features of all gold-placers, especially those of the detritus of weathering in place, where the agency of running water cannot be adduced, and the accumulations of gold at the contact of the loose and the solid material must be explained by its sinking through the former.

Stream Detritus.—The detrital deposits produced by running water are generally characterized by the predominance of permeable material, such as sand, gravel, etc. Under this covering mass lies the solid, impermeable "bed-rock" or "rim-rock" of the Americans, the *plotik* or *posva* of the Russians; and in all the gold-fields of the world, the richest pay-deposits are found, as a rule, at the border between the cover and the bed-rock. If the latter is decomposed, fissured, or otherwise loosened, the fine gold will sink into it, mak-

ing it sometimes rich enough to be mined and concentrated; and this occurs without regard to the petrographic character of the rock. Thus in the Ural, palæozoic schists, limestone and eruptive rocks indifferently are charged with gold. This circumstance indicates also the error of the assumption that these bed-rocks originally carried gold.

But layers of impermeable material sometimes occur in the cover, as, for instance, lava-beds in Australia and California, or, in general, solid conglomerates and clays. In such cases there is often a concentration of gold on the more solid layer, called in America the "false bottom," and in the Ural *loznyj plotik*—that is, a material erroneously taken for the bed-rock. There are often in the detrital cover two or more such gold-bearing layers, which are easily explained on the theory above suggested. The hypothesis of a natural concentration in running water is embarrassed by the fact that the material of gold-placers shows no arrangement according to size, but consists, as a rule, of elements of all sizes.

The movement of the elements of a loose mass has been already pointed out by W. C. Kerr,* who admits the possibility of the sinking of the heavier particles, as does also A. G. Lock,† though this is only in a passing remark, and without indication of its far-reaching importance. Lock says:

"The superior weight of the precious atoms would cause them to sink through the moist surrounding matters, till a hard layer was met with. The occurrence of this process would constantly add to the deposit, the gold always gravitating towards the bottom, quickly or slowly, according to circumstances."

It seems to me that this idea must have impressed itself upon other impartial observers also; and I can only wonder that it has not been more frequently expressed.

R. Helmhacker has recently communicated some observations in the Altai region of Siberia, such as the sinking of heavy metallic objects in the loose wash, which confirm the above views. Among other things, he identified grains of metallic lead formed in the gold-placers, as shot, scattered in hunting, which had sunk into the earth.

As is well known, auriferous detritus occurs not only in present but also in ancient river-beds, long since dry; and since, in the latter, the remains of diluvial animals, such as the mammoth, etc., have been found, a distinction has been made between alluvial and

* "The Gold-Gravels of North Carolina," *Trans. A. I. M. E.*, 1880, viii., p. 462.
† *Gold, its Occurrence*, etc., London, 1882, p. 916.

diluvial gold-deposits. But discoveries of yet older organic remains have shown that such gold-deposits were formed in still more ancient periods. The old river-beds of California cross the present streams, and the auriferous detritus of the former is covered with thick lava-beds—a feature which may be observed in Australia also. During the deposition of the gold, therefore, conditions very different from those of the present day must have obtained.

In another respect, also, the relation between ancient and modern river-beds is sometimes peculiar. The late channels have been rendered by erosion deeper than the older ones. But on the eastern slope of the Ural this is almost totally reversed. The diluvial gold-deposits characterized by the remains of the mammoth often lie below the water-level of the present streams, so that the latter must be diverted in order to mine the ancient beds. This condition apparently extends throughout the whole Siberian plain, and may be taken as evidence that the erosive energy of its rivers has decreased since the Diluvial period, their fall having been reduced, either by the accumulation of the erosion-detritus or by changes in the relative altitude of the Ural range.

The eastern slope of the Ural is characterized by numerous lakes and swamps along the tributary streams, and a number of these contain auriferous detritus, which has been mined for gold.

Marine Detritus.—In some regions, the auriferous detritus, after being repeatedly deposited and again swept away, to be re-deposited further down the valleys, has at last reached the sea. The coast of Oregon, in western North America, and Vladivostock, in southeastern Siberia, are examples. Here the ebb and flow of the tide operate very nearly on the principles of artificial ore-dressing; and one would think that a concentration of the heavier particles might be thus effected. But it does not appear that such effects have been recognized hitherto.

Kackar District, in the Ural.—At the beginning of this section, in the discussion of features of auriferous erosion-detritus, some characteristics of the Ural placers were described. A few additional particulars concerning them may be of interest. The gold-bearing stratum occurs at no definite depth. As a rule, the whole of the barren or poor cover is stripped off and thrown aside, before the auriferous layer, thus laid bare, is systematically attacked. Open cuts (*Razregy*) in the surface, of greater or less depth, are thus created, and are usually left to be filled up by the rivers. In the district of Kackar, already mentioned, in the Southern Ural, orig-

inal deposits ("root-deposits") of gold have been repeatedly found in the bottom of these cuts. They were well-defined quartz-veins, carrying in the upper zone free gold, but at greater depth sulphides and arsenides rich in gold. In the case I have in mind, the original open cut extended for a considerable distance along the strike of the vein; but the bed-rock (which was at the same time the country-rock of the vein) was much decomposed, so that the difference between detritus and bed-rock was not strikingly evident; and the placer-working passed only by gradual stages into vein-mining.

Hysteromorphous gold-deposits may thus be said, in a general way, to occur in the following positions:

1. In the simple detritus of weathering, immediately upon the original deposit (root-deposit).
2. Mixed with the sand and gravel of present streams.
3. At certain points in the river-bottom, into the crevices and fissures of which the gold has sunk.
4. Mixed with the impermeable material of older water-courses, through which the gold could not sink.
5. On the false bottoms or bed-rocks.
6. On the true bed-rock.
7. In the decomposed bed-rock itself.

In considering the chemical changes of the outcrops of deposits (including, of course, those which give rise to hysteromorphous derivatives) we have seen that sulphides suffer total decomposition, and that of their constituents only the unoxidizable metals, such as gold and platinum, remain unaffected. Silver-ores and native silver, being attacked by the chlorides of the vadose circulation, are consequently not found in hysteromophous deposits. But gold occurring in nature is for the most part alloyed with silver. The gold from the veins of Budweis, in Bohemia, contains by weight about two parts of silver, and that of Transylvania contains by weight more than three of silver, to ten of gold. Whenever I have had opportunity to compare the gold of an original or root-deposit with that of its derived placer, I have found the latter to be of greater fineness, that is, to contain less silver. I am strongly inclined to ascribe this phenomenon to the prolonged contact with water containing chlorides. The dull surface of placer-gold and its frequently spongy interior structure, as compared with the luster and solidity of "quartz-gold," favor this explanation.

Platinum-Placers.—Detrital deposits of platinum have been, until

recently, particularly observed in the Ural only, from which the main supply of platinum was derived. Additional localities are now reported in the Altai district of Siberia and in Canada and British Columbia. In the Tulameen district, it is said, the hydraulic method of mining has been introduced for platinum. I have been unable to obtain detailed information concerning the features of these deposits.

In the Ural, and particularly in its most productive district, that of Niznyj Tagil, the conditions closely resemble those of gold-deposits. The richest platiniferous layers are on the true bed-rock. Platinum and its associates, palladium, nevjanskite and siserskite, being found to occur occasionally adhering to olivine and chromite, it was inferred that they were derived from the serpentine, which is itself a secondary product from olivine-rocks. More recently, platinum is said to have been found in an olivine-gabbro not yet metamorphosed; but whether the metal is a primary or an exotic constituent, can as yet scarcely be declared with certainty.

Formerly no other occurrence of platinum than the native metal was known; but now a platinum-ore has been found in the Sudbury district, Canada, namely, sperrylite, a compound of platinum and arsenic. Since this is certainly xenogenous, the question as to the original sources of platinum-deposits is advanced to a new phase by its discovery.

Tin-Placers.—In connection with the occurrence of tin as cassiterite in detrital deposits, the specific gravity (6.97) of this mineral, nearly equalling that of iron, and the great resistance which it offers to natural agents of decomposition, doubtless play the principal part. Of the numerous and various associates of cassiterite in its original deposits, none, except quartz, are equally able to resist decomposition; and the consequence is, that the detritus, both of weathering and of erosion, from the outcrops of such deposits, contains, besides the products of the decomposition of these other minerals, chiefly quartz and pieces of cassiterite. The latter, by reason of its high specific gravity, will tend to sink through the lighter detritus and be concentrated near the bed-rock.

The stanniferous detrital deposits of Bohemia and Saxony, as well as Cornwall, were long since exhausted; those of Australasia, the South Sea islands and South America are still worked. According to the special monograph of Dr. E. Reyer*, the richest layers are in

* *Zinn, eine geol.-montan.-historische Monografie*, Berlin, 1881, p. 203.

fact found at the bottom of the detritus, immediately on the bed-rock.

With regard to the geological age of the detrital tin-deposits, the rule stated for gold generally obtains, namely, they are for the most part diluvial, yet have sometimes been formed in earlier periods. Thus, at Platten, in Bohemia, a tin-placer, which has been worked under a bedded flow of basalt, and the detrital deposits of Annaberg in Saxony, which underlie the basalt of the Scheibenberg, were doubtless formed in Tertiary times.

The original or root-deposits of tin have been hitherto quite generally considered as very old formations, connected with the eruptions of granite and felsite-porphyry.

Recently, however, tin has been found in the Mesozoic limestones of Campiglio Maritima; and it has been shown, moreover, that the root-deposits of tin in Mexico and Bolivia occur in trachytes and andesites, erupted during the Cretaceous or Eocene. Dr. A. W. Stelzner has recently published a notice of the latter occurrence,* and promised a more elaborate description. He says (p. 533):

"The part played in geological history by the tin-ore of Bolivia, contrasts sharply with that which has been observed in the Erzgebirge of Saxony and Bohemia, and in Brittany, Cornwall, East India, Australia, Tasmania, and the United States of America, and which has hitherto been willingly regarded as the exclusive method of tin-occurrence. The Bolivian tin-ore does not constitute aureoles surrounding plutonic granite, and characterized by the contemporaneous presence of minerals containing boron and fluorine. On the contrary, it can only be considered as produced, simultaneously with precious silver-ores and sulphides of copper, iron, lead and zinc, by precipitation from mineral springs, which were connected in point of time, and perhaps also as effects, with outflows of Cretaceous or Lower Tertiary volcanic rocks."

c. *Hysteromorphous Deposits of the Older Geological Formations.*

Twenty-five years ago, at a time when no deposits of this kind were known, in an article on the continuance of ore-deposits (especially of gold) in depth,† I prophesied their discovery. They have since been observed in different gold-districts. I refer to the characteristic secondary deposits in quartz conglomerates, indicated by their stratigraphical positions and their contained fossils to be of considerable geological age. Such occurrences are often called simply cement-beds, as are the conglomerates of cemented gravel in recent placers; and it is difficult in cases where, as in Australia, this

* *Zeitsch. d. deutsch. geol. Gesellsch.*, xliv., 1892, p. 531.

† *Oesterr. Zeitsch. f. B.-u. H.-wesen*, xv., 1867.

term is frequent,* to infer the age of the corresponding conglomerates. It is, however, in some cases unquestionable that these cements actually represent old formations—chiefly Palæozoic—and are therefore hysteromorphic products from still older primitive deposits.

Deadwood, Dakota.—One of the best described occurrences is that of Deadwood and Blacktail gulches, in the Black Hills of Dakota.† It is a conglomerate bed, passing upwards into sandstone, and belonging, according to the contained fossils, to the Potsdam sandstone (Cambrian). It is by no means a river-deposit; on the contrary, the fossils indicate a shallow marine basin. The series lies very flat upon crystalline schists; is at most 100 feet (30 meters) thick, and is covered by a layer of porphyry, which has most probably protected it from erosion. Fig. 100, a section given by Mr. Devereux (*op. c.*, p. 468), shows how the deposit is exposed and rendered accessible on the sides of Deadwood and Blacktail gulches, which cut through into the underlying schists.

The conglomerates of pebbles of quartz, schist, and hematite which lie at the base of this Cambrian series carry partly coarse gold, under such circumstances that there can be no doubt of its secondary origin. It came probably from the Homestake vein near by. The auriferous detritus is about 2 meters (6.6 feet) thick, and the portions next to the underlying rock are the richest; so we have here the relation of the "true bed-rock." If my theory be correct, that the gold reached this position by sinking through the lighter detritus, it might be said that the gold was deposited not *with*, but *after*, the detritus, and consequently that the Cambrian fossils do not prove the Cambrian age of the gold-deposition. Such an objection might perhaps have weight in other cases of the kind, but in this case, the bed being covered by a porphyry overflow, and hence not at all exposed to later deposits, the objection has no force.

The Black Hills contain representatives of the three principal types of gold-occurrence, namely, gold-bearing veins and ancient and recent detrital deposits. The paper of Mr. Devereux is also very interesting in other respects—for instance, with regard to the explanation of the differing fineness of vein- and detrital-gold, and with regard to the traces of chemical action in the detrital deposits.

* See, for example, Mr. Lock's *Gold*, etc., already cited.

† W. B. Devereux, "The Occurrence of Gold in the Potsdam Formation, Black Hills," *Trans. A. I. M. E.*, 1882, x., 465.

Australasia.—The data from Australasia concerning this class of deposits are less conclusive. In 1876 Wilkinson observed in the Tallawang district of New South Wales that the Tertiary detrital deposits received their gold from Carboniferous conglomerates. These conglomerates were associated with sandstones and slates, in which occurred a fossil plant peculiar to the Carboniferous of New South Wales. The gold occurred in pretty coarse, rounded grains, and on one occasion a nugget was found weighing 5 ounces (155 grammes). Similar conditions are said to obtain in the Hawkesbury rocks, at the North Shore, Sydney, at Govett's Leap, and in the conglomerates of the Coal-Measures in the southern district. Gold is also reported in the Coal-Measures at Peak Downs in Queensland, near Hobart Town in Tasmania, and in New Zealand.*

The question, whether these deposits of gold were really made simultaneously with that of the detritus in the Carboniferous period, may be decided by the circumstance that the conglomerates are or are not covered by Carboniferous strata. In the latter case, it is possible that the gold may have sunk into the gravel at a later period.

South Africa.—In South Africa, at Witwatersrand in the Transvaal, ancient detrital deposits have yielded a considerable gold-production. According to E. Cohen,† the Witwatersrand consists of sandstones (which resemble closely that of Table mountain at the Cape of Good Hope) and dolomites of high age—undoubtedly Palæozoic. Conglomerates of the same age, intercalated among these strata, occur in the vicinity of Johannesburg in several nearly parallel outcrops, and are for certain distances tolerably rich in gold. They are composed mostly of quartz pebbles, sometimes with fragments not entirely rounded, which are united by a strong, ferruginous, arkose-like cement. The quartz pebbles are sometimes porous and impregnated with hydrated ferric oxide, thus presenting the peculiar corroded appearance so characteristic of auriferous quartz. The gold occurs chiefly in the cement, immediately next to the pebbles. It is mostly coarse-grained, and sometimes even crystalline. The latter circumstance has raised the question whether the gold has not here been chemically precipitated, and hence, whether these are detritus-deposits at all. My standpoint in this discussion, as I have remarked at the end of the section on chemical effects

* Lock's *Gold*, etc., pp. 515, 516. See also R. Daintree's "Note on Certain Modes of Occurrence of Gold in Australia," *Quart Jour. Geol. Soc.*, 1878, xxxiv, p. 435.

† "Goldführ. Conglom. in Südafrika," *Mitth. d. naturw. Ver. f. Neupommern*, etc.

in the upper region, is like that of E. Cohen. I do not deny the presence of chemical influences in the detrital deposits, although I have personally not happened upon them. So far as I can judge from the treatises of A. R. Sawyer* and Charles A. Alford,† and from a specimen of the Witwatersrand conglomerate, kindly sent to me by A. H. Halder of Pietersburg, it is my opinion that the gold was mechanically brought into the conglomerates from still older auriferous quartz-veins occurring in the rocks which form the basis of this Palæozoic formation; and since the idea of a later entrance of the gold is excluded by the almost vertical position of the conglomerate beds near Johannesburg, I suppose the gold to have been deposited at the same time as the detritus. The greater part of the gold, as has been said, occurs in the cement. There are no vein-like deposits whatever in the conglomerate; and the only chemical changes which could be presumed are confined to the decomposition of pyrites and the segregation of its contained gold.

According to a foot-note in Phillips's *Treatise on Ore-Deposits* (p. 2), gold is washed out of granular conglomerates of the Lower Carboniferous at Bessèges, Département du Gard, France.

Bohemia.—In the region of Trautenau, in Bohemia, I observed at Gabersdorf and Goldenöls considerable traces of ancient placer-mining, partly in the valley-bottom, partly on the slope, which consisted of old Permian and Carboniferous conglomerates. These remains looked exactly like other gold-workings in Bohemia, and I could only explain their situation by supposing that this was another case of auriferous Palæozoic detritus. The same may be said of another enigmatical gold-occurrence, at Stupna in Bohemia, where in 1593 a gold of unusual fineness (0.954) for Bohemia was produced, and must have come from a detrital deposit. The ancient miners penetrated through bedded flows of melaphyr. The waste-dumps are composed of pebbles from Permian conglomerates. It is therefore possible that these mines were operated upon auriferous Permian conglomerates.‡

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* "The Witwatersrand Gold-field." *Trans. N. Staffordsh., Inst. M. and Mech. E.*, 1893.

† *Geological Features of the Transvaal*, London, 1891.

‡ F. Pošepný, "Ueber einige wenig bekannte, alte Goldbergbaue Böhmens." *Oesterr. Z. f. B.-u. H.-wesen*, xxxvii., 1889.

Description of Figures.

Fig. 1.—Erosion of a channel in rock-salt, at Máros Ujvár, Transylvania. I, impermeable rock; S, rock-salt; H, hydrostatic head of vadose circulation.

Figs. 2 and 3.—Course of vadose circulation, as affected by the nature of the rocks. S, soluble, I, insoluble rock; H, hydrostatic head; *a*, entrance, *z*, outlet; *a b c z*, natural curve of water-circulation, if I did not intervene; *a d z*, actual path under or over I.

Fig. 4.—Geode of *Eisenopal* (jasp-opal), showing the filling of a cavity in which air or gas is present, besides the liquid.

Fig. 5.—Diagrammatic representation of deposits in a limestone cavern. (Deposits white; empty space, black.)

Fig. 6.—Division of ground-water by fissures and permeable strata.

Fig. 7.—Conventional representation of an artesian well.

Fig. 8.—Spring-mounds at Arczó near Korond, in Transylvania.

Fig. 9.—Upward erosions in building-stone in the walled pit of a spring at Bourbonne-les-Bains.

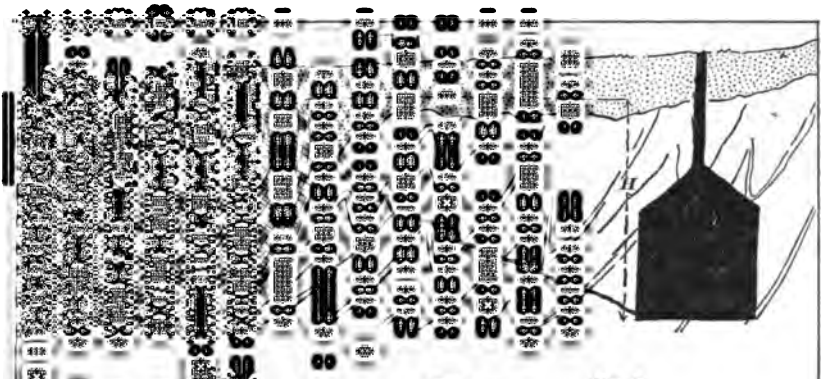


Fig. 3

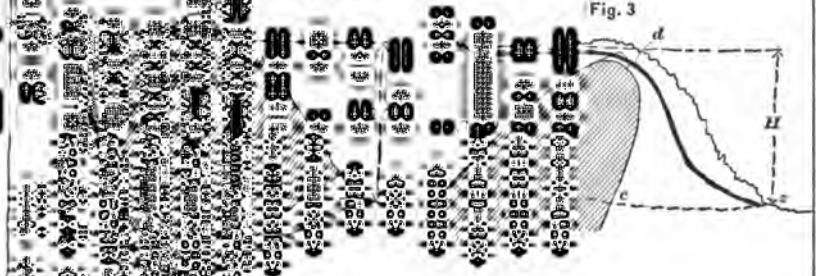


Fig. 7

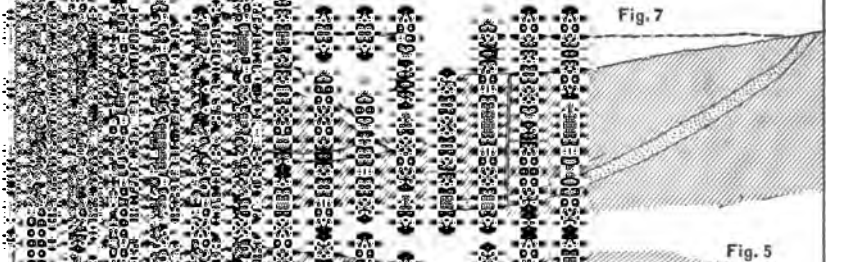
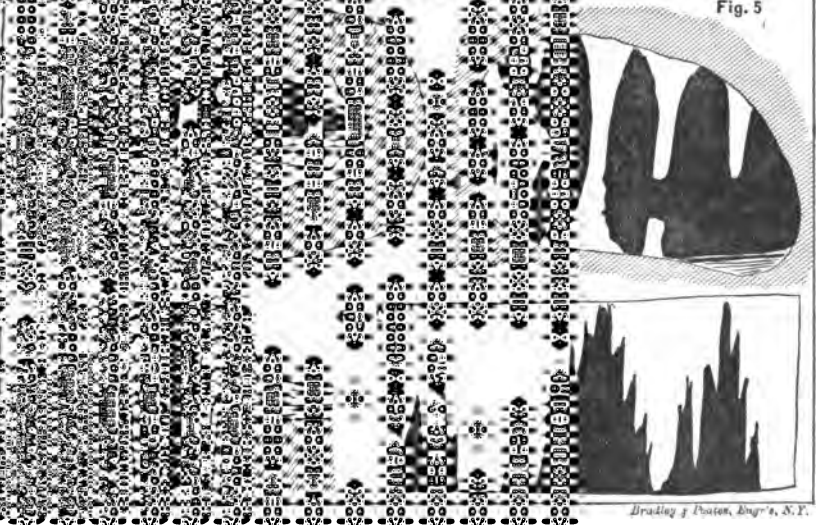


Fig. 5



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Description of Figures.

Fig. 10.—Deposition of cinnabar and opal in basalt at Sulphur Bank, Cal. Sketch at the surface by F. Pošepný.

Fig. 11.—Similar deposition at the same mine, in sandstone, at greater depth (J. Le Conte).

Fig. 12.—Carlsbad *Sprudelstein*.

Fig. 13.—Pisolite with pyrite crusts, from Hammam Meskoutine.

Figs. 14, 15 and 16.—Pisolites formed by dripping solutions at Offenbánya.

Fig. 17.—Cocarde-ores, a correction of the illustrations of Cotta (*Erzlagerstättenlehre, Erster Theil*, 33) and Daubrée (*Les eaux aux époques anciennes*, p. 64).

Fig. 18.—Gold specimen from the Katrontza ore-body, Verespatak.

Fig. 19.—A crusted rock-nucleus, from Raibl.

Fig. 20.—Boiler-scale.

Figs. 21 and 22.—Fragments of rock and older crusts, surrounded by later crusts, from Zellerfeld (J. C. L. Schmidt).

Fig. 24.—Gold-aggregates, surrounded by crusts of calcite, rhodonite, siderite and quartz, from the Rákosi Mangan ore-body, Verespatak.

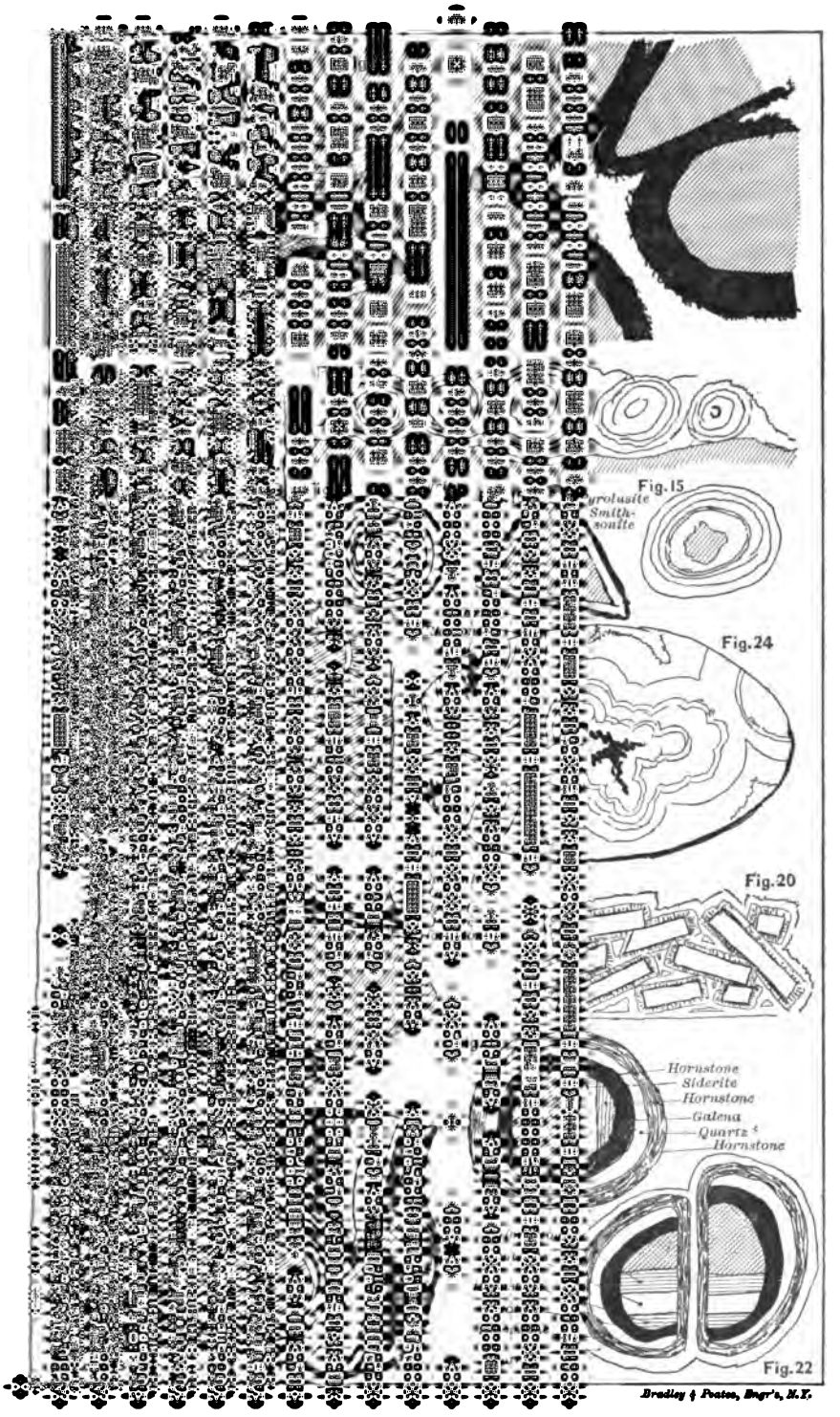
Fig.15
Smith-
sonite
Fig.24
Fig.20
Horustone
Siderite
Horustone
Galena
Quartz
Hornstone
Fig.22
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Description of Figures.

Figs. 25, 26, 27 and 28.—Sections of stalactites of galena, blende and pyrite, so-called "pipe-ores," with hollow axis, from Raibl.

Fig. 29.—Section of rhodonite stalactites, with axis of gold-aggregates, from the Hungarian National Museum.

Fig. 30.—View of the same.

Fig. 31.—Section of a similar stalactite in the author's possession, from the Rákosi Mangan ore-body. Enlarged to twice the natural size.

Figs. 32, 33, 34, 35.—Sections of ore-channels in the limestone of the Vallé mines, Missouri (J. R. Gage).

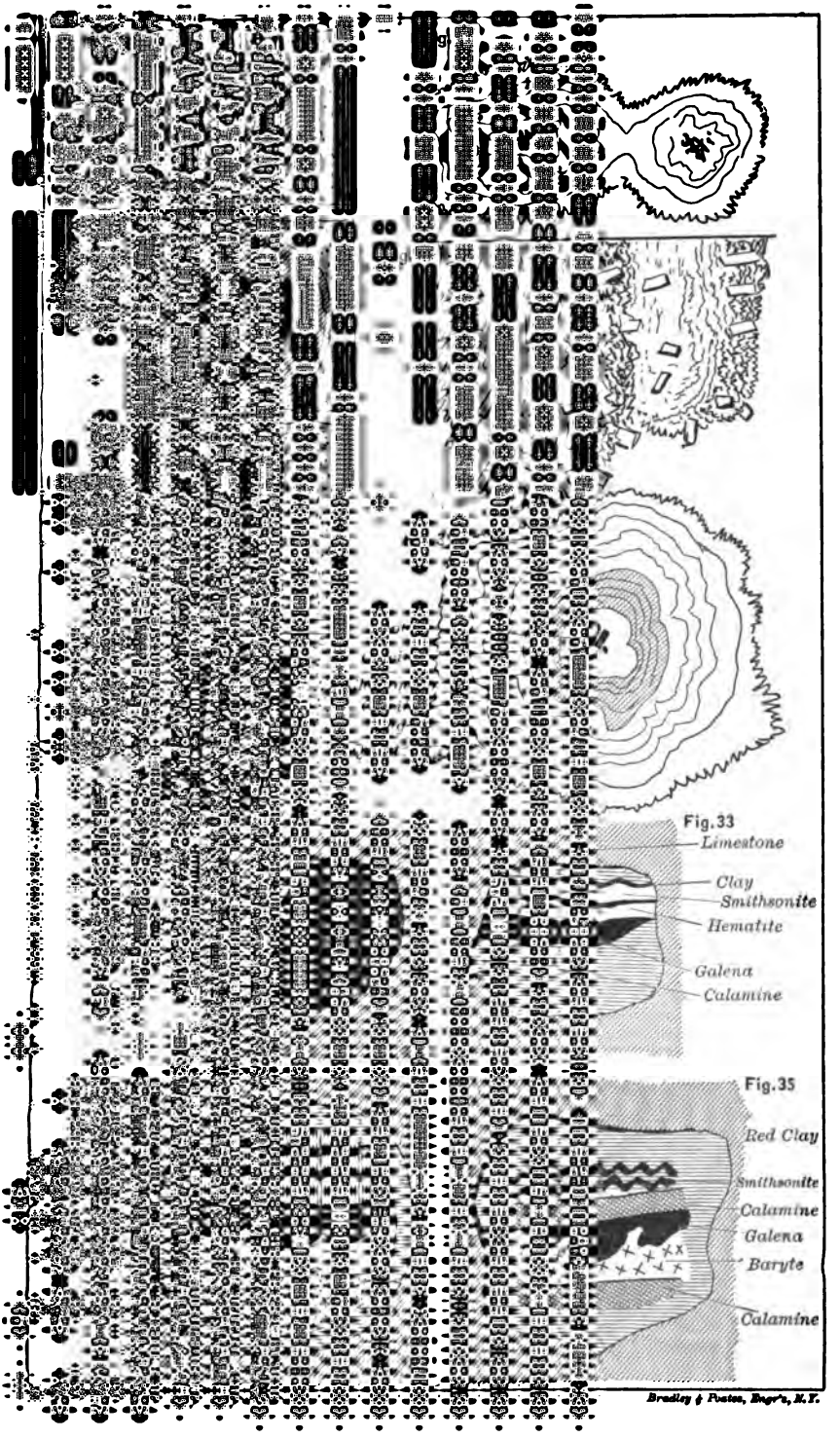
Fig.33
Limestone
Clay
Smithsonite
Hematite
Galena
Calamine
Fig.35
Red Clay
Smithsonite
Calamine
Galena
Baryte
Calamine
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Description of Figures.

Fig. 36.—Plan showing gold-bearing veinlets, striking E. to W., in granite (beresite) striking N. to S., at Beresov.

Fig. 37.—Network of veins and vein-clay-slates in the Clausthal district. Localities: *a*, Lautenthal; *b*, Bockwiese; *c*, Festenberg; *d*, Ober-Schulenberg; *e*, Wildemann; *f*, Zellerfeld; *g*, Clausthal.

Fig. 38.—Network of veins and *Ruscheln* in the St. Andreasberg district. *Ruscheln*: *a b*, Neufang; *a c*, Edelleut; *d f e*, Silberburg; *f g h*, Abendroth Veins: *l l*, Samson (*i*, Samson shaft); *k k*, Bergmannstrost.

Fig. 39.—Section through the Franz Joseph shaft, Przibram, Bohemia. A B, sea-level, heights above and below which are given in meters on the left. The Roman numerals on the right indicate the vein-levels. *a*, post-Cambrian slates; *b*, Cambrian sandstone; *c*, *c*, faulted stratum of adinole; *d*, *d*, diorite dikes; *m*, Martyr vein; *u u*, Marie Hilf vein; *v*, *v*, *v*, Sefcin vein; *w w*, West-dipping vein; *s s*, Franz Joseph shaft.

s
m
d
I
II
dd
d
d
d
V
VII
VIII
IX
X
b
XII
XVII
B
XIX
b
w
XXI
XXIII
c
XXV
XXVI
w
XXVIII
d
e
XXX
s
XXXI
d
b
m
c
l
h
c

Description of Figures.

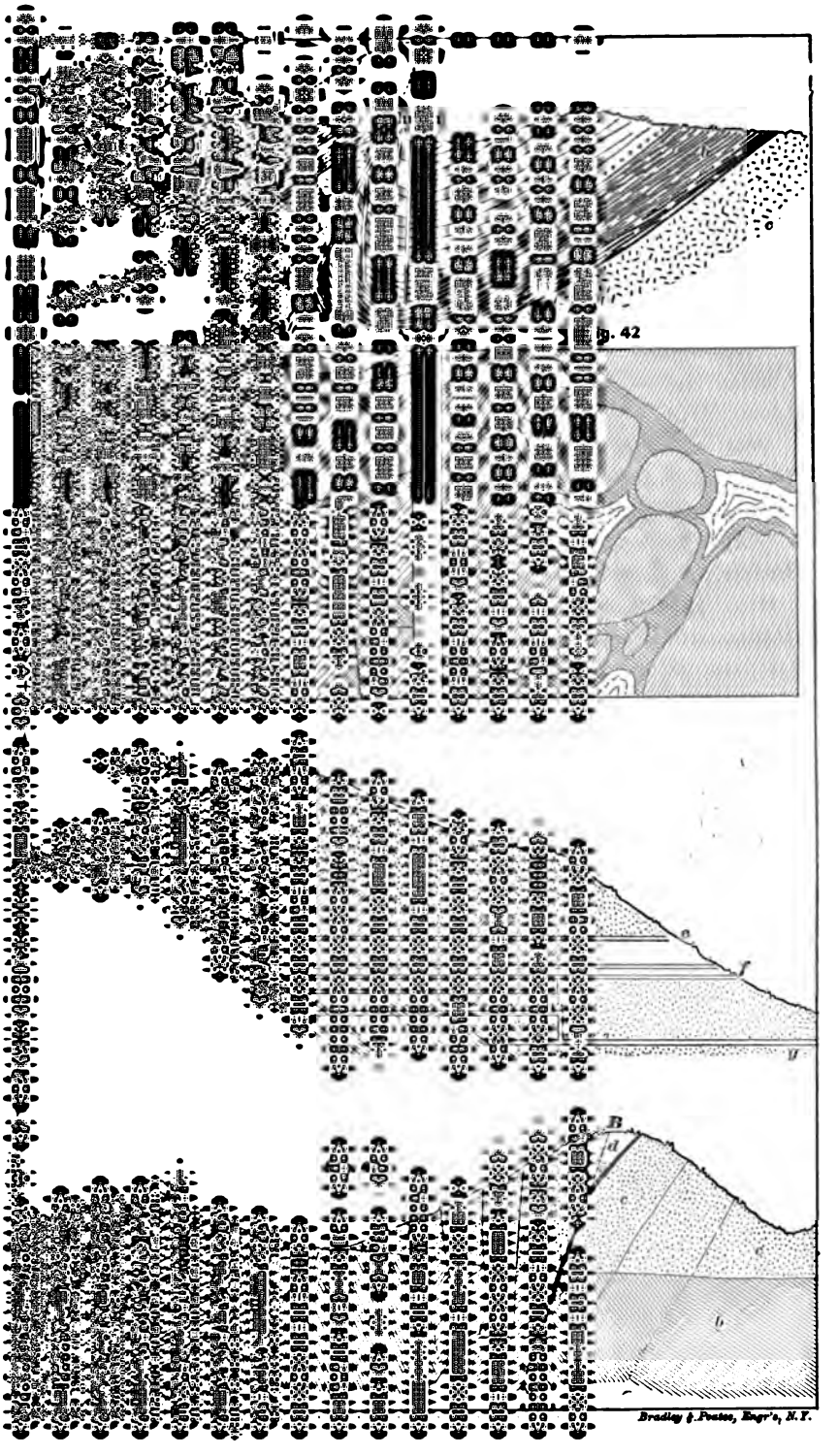
Fig. 40.—Ideal section through Bohutin, near Przibram. *a*, Cambrian sandstone; *b*, pre-Cambrian schists; *c*, granite; *d*, main fault-fissure; *e e*, diorite dikes. (Note: At Przibram itself the pre-Cambrian schists constitute the hanging-wall of the main fault-fissure to the entire depth of the mines—about 1110 meters, or 3600 feet.)

Fig. 41.—Diagrammatic representation of the structure of the Verespatak ore-bodies (Volbura), showing the ore replacing the washed-out cement of a breccia, mostly of porphyritic fragments.

Fig. 42.—The same, only conglomerate instead of breccia.

Fig. 43.—Vertical S. to N. section through the Vulkoj mines, showing the supra-position of andesite upon the shaly sandstone. *a a*, Nepomuk adit; *b*, sandstone; *c*, andesite; *d*, Corabia open-workings; *e*, Jeruga adit; *f*, Peter-Paul adit; *g*, Hermann adit.

Fig. 44.—Vertical E. to W. section through the gold-mines of Botesiu and Vulkoj. A, Botesiu; B, Vulkoj; *a*, Nepomuk adit; *b*, sandstone; *c*, andesite; *d*, Corabia open-workings; *j*, Jeruga vein.



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Description of Figures.

Fig. 45.—Section in fourth level of Peter Stehend vein, Freiberg. *a*, decomposed country-rock; *b*, quartz, with brown-spar, pyrites, blende, and silver-ores. (C. G. A. Von Weissenbach, No. 2 in his work.)

Fig. 46.—Section on third level of Adlerflügel Stehend vein, Freiberg. *a*, gneiss fragments; *b*, older vein-formation; *c*, later quartz vein-matter; *d*, gneiss. (Weissenbach, No. 21 in his work.)

Fig. 47.—Section on third level of Gnade Gottes Stehend vein, Freiberg. (Weissenbach, No. 22.)

Fig. 48.—Section on thirteenth level of Adalbert Liegend vein, Przibram. *a*, galena and calcite; *b* (or, more precisely, the irregular mass shown to the right of *b*) zinc-blende; *c*, sandstone. (J. Zadrazil, No. 52.)

Fig. 49.—Section on thirteenth level of Adalbert master-lode, Przibram. *a*, siderite; *b*, calcite; *c*, quartz; *d*, galena; *e*, diorite. (J. Zadrazil, No. 5.)

Fig. 50.—Section on twenty-ninth level of Adalbert master-lode, Przibram. *a*, calcite; *b*, silicified (*verquarzte*) vein-matter; *c*, quartz; *d*, diorite. (J. Zadrazil, No. 21.)

Fig. 51.—Section on adit of Hildebrand vein, Joachimsthal. *a*, mica-slate; *b*, dolomite; *c*, *c*, proustite; *d*, dolomite with pyrite; *e*, uraninite. (J. Nemecek, No. 11.)

Fig. 52.—Section on tenth level of Junghäuerzechen vein, Joachimsthal. *a*, *a*, dolomite and calcite; *b*, *b*, mica-schist; *c*, basalt-wacke; *d*, chalcopyrite; *e*, proustite. (J. Nemecek, No. 5.)

Fig. 48

Description of Figures.

Fig. 53.—Specimen from the Drei Prinzen Spat vein, in the eighth level of the Churprinz Friedrich August mine, Freiberg, Saxony; $\frac{1}{6}$ nat. size; *a*, quartz with disseminated galena and blende, indistinctly crustified—from the older vein; *b*, fluorite with quartz; *c*, barite in thin crusts; *d*, gray earthy mass of the later vein, very distinctly crustified; *e*, the latest fault-fissure.

Fig. 54.—Copper-deposit at Prettau in Tyrol. Sketch of the roof of the Ottilie level.

Fig. 55.—Ditto; side of the same level.

Fig. 56.—Ditto; vertical section in the plane of the pitch, which descends nearly westward, the course of the strata being E. to W., and the dip steep to South. Adits and levels: *a*, Peter; *b*, Jacob; *c*, Marx; *d*, Johann; *e*, Kristof; *f*, Nikolaus; *g*, Ignatz. The three levels below *g* are the Ottilie, Karl, and Hugo.

Fig. 57.—Ditto; horizontal projection, showing approximately the position of the ore-bodies on the different levels: *a* to *g* as in Fig. 56; *x y*, strike; *y w*, true dip of strata; *y z*, pitch of ore-shoot.

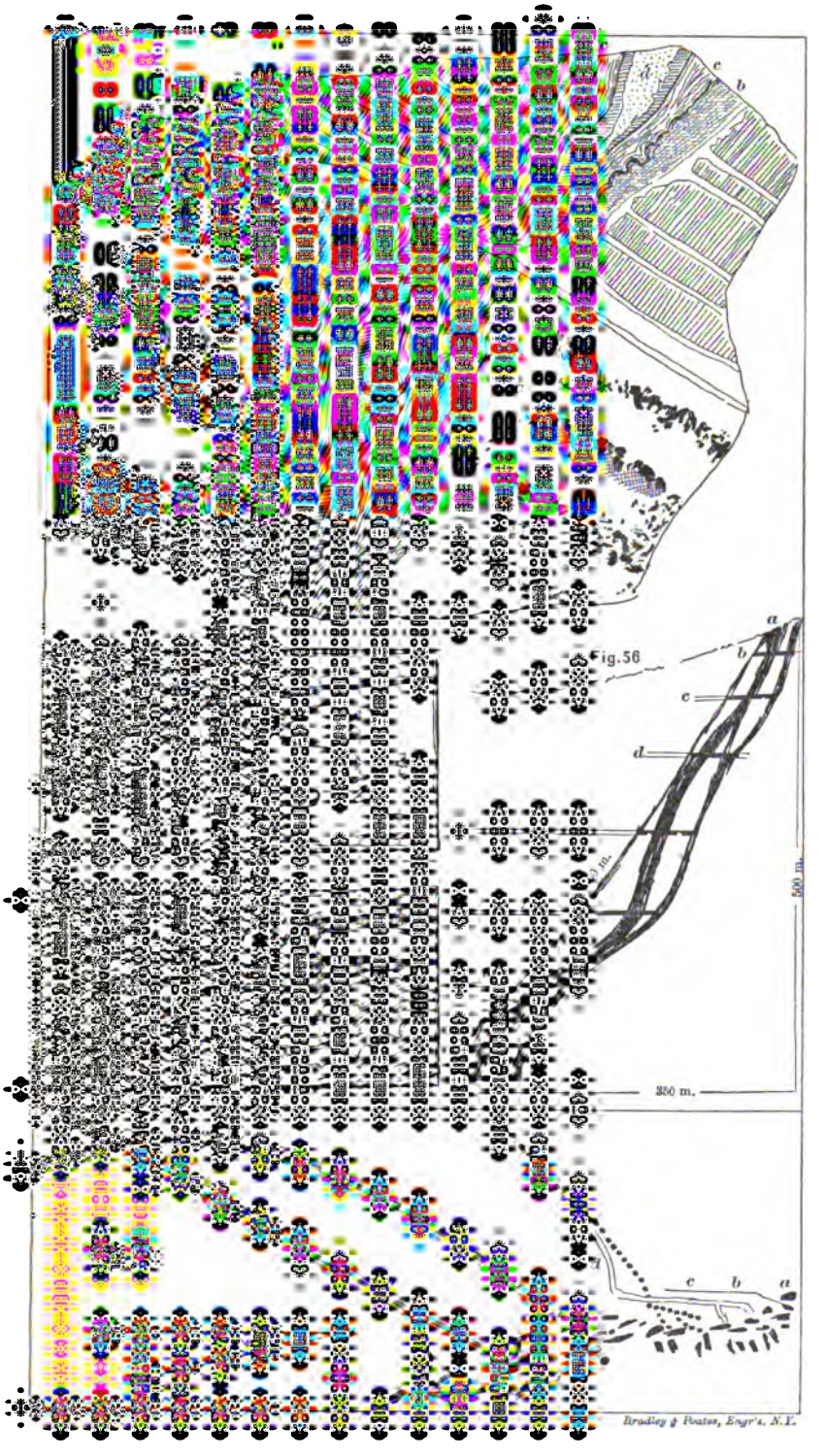

Fig. 56

Description of Figures.

Fig. 58.—Surface-geology of the vicinity of the Comstock lode. B, basalt; L H A, later hornblende-andesite; A A, augite-andesite; E H A, earlier hornblende-andesite; D*b*, diabase (the black dike is earlier diabase); Q P, quartz-porphyry; F P, felsitic quartz-porphyry; D*r*, diorite; G*r*, granite. (G. F. Becker.)

Fig. 59.—Vertical cross-section through Union shaft. (G. F. Becker.) G D, granular diorite; E D, earlier diabase.

Fig. 60.—Vertical cross-section through C. and C. shaft. (G. F. Becker.)

Fig. 61.—Vertical cross-section through Yellow Jacket shaft. (G. F. Becker.)

Fig. 62.—Vertical cross-section through Belcher shaft. (G. F. Becker.)

Fig. 63.—Vertical section on line of Sutro tunnel. I, II, III, and IV, Sutro tunnel shafts; *s s*, lines of solfataric action; *v*, vein-material. (G. F. Becker.)

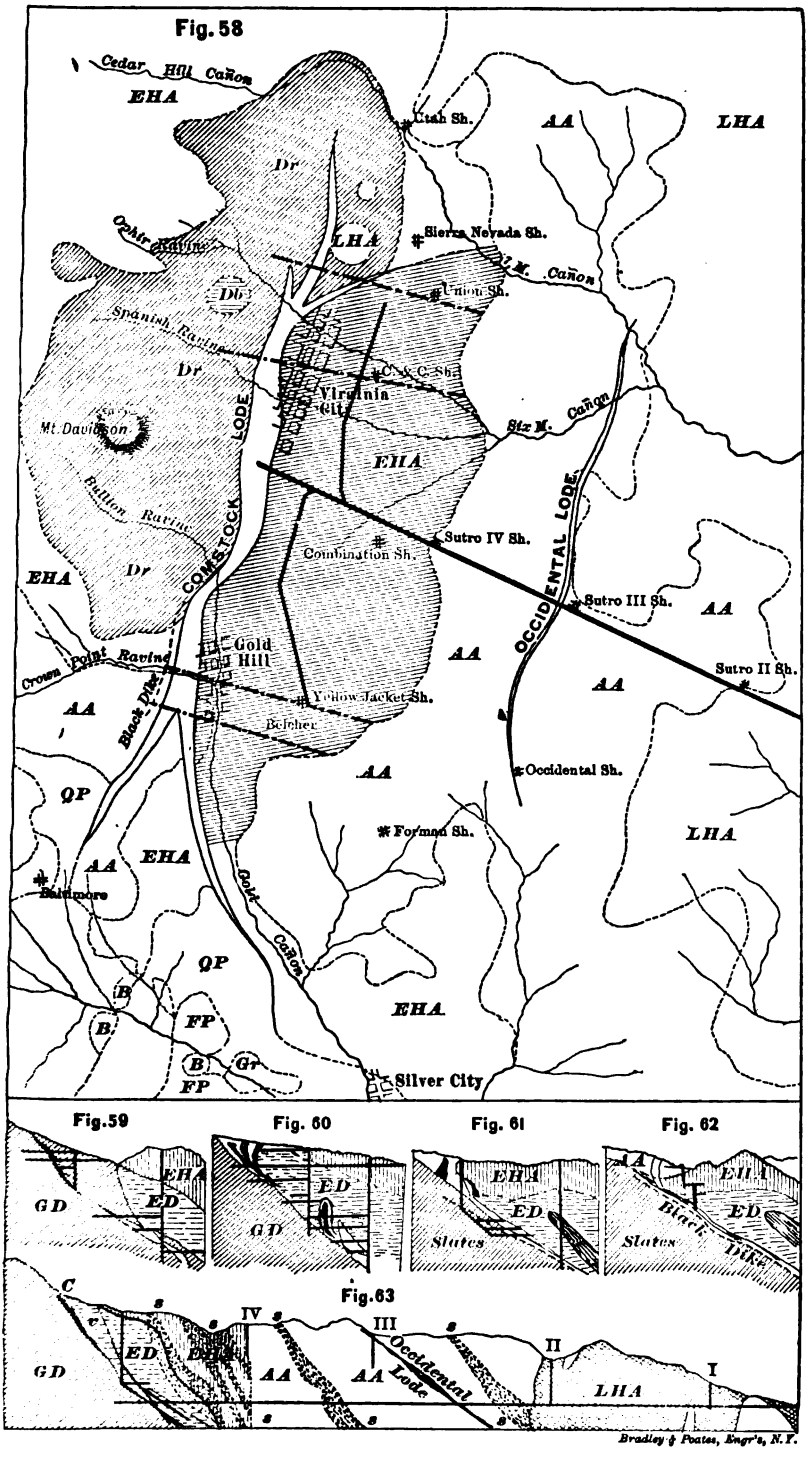
Fig. 58
Cedar Hill Cañon
EHA
Utah Sh.
AA
LHA
Dr
Ophir Ravine
LHA
Sierra Nevada Sh.
Union Sh.
Cañon
Db
Spanish Ravine
Dr
C. & C. Sh.
Virginia City
Mt. Davidson
COMSTOCK LODE
Six M. Cañon
EHA
Bullion Ravine
Sutro IV Sh.
Combination Sh.
OCCIDENTAL LODE
EHA
Dr
Sutro III Sh.
AA
Gold Hill
AA
Crown Point Ravine
Sutro II Sh.
AA
Black Dike
Yellow Jacket Sh.
AA
Belcher
AA
Occidental Sh.
QP
Forman Sh.
LHA
AA
EHA
Baltimore
Gold Cañon
QP
B
B
FP
EHA
B
Gr
FP
Silver City
Fig. 59
Fig. 60
Fig. 61
Fig. 62
GD
EHA
ED
GD
ED
EHA
ED
Slates
AA
EHA
ED
Black Dike
Slates
Fig. 63
C
s
IV
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III
s
II
I
GD
ED
EHA
AA
AA
Occidental Lode
LHA
s
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Description of Figures.

Fig. 64.—Vertical E. and W. section through the mines of Valle Sacca, near Rézbánya, Hungary. *a*, sandstone; *b*, Jurassic limestone; *c*, Liassic limestone; *dd*, crystalline limestone; *e*, syenite; *f*, 3d adit; *g*, 4th adit; *h*, new Anton adit; *i*, Juliana ore-body; *k*, Marianna ore-body; *l*, Anton ore-body; *mm*, parallel intercalated dike; *nn*, Reichenstein ore body; *oo*, dikes.

Fig. 65.—Vertical longitudinal section of Reichenstein ore-body, Valle Sacca, Hungary. *nn*, ore-body; *b*, limestone; *d*, 1st adit; *e*, 2d adit: *f*, 3d adit.

Fig. 66.—Diagram showing the S. W. pitch of the Reichenstein ore-body, the dikes dipping W. *x y*, course of dikes; *x w*, dip of dikes; *x z*, pitch of ore-shoot.

Fig. 67.—Vertical N. and S. cross-section of the Government mine at Raibl, Carinthia. *a*, Raibl slates; *b*, ore-bearing limestone. Adits: *c*, Johann; *d*, Frauen; *e*, Sebastian; *f*, Franz. II., IV., VI. and VII., positions of levels numbered upwards from Johann adit.

Fig. 68.—Vertical N. and S. section through the Struggl mine at Raibl. *a*, slate; *b*, ore-bearing limestone; *f*, Franz adit; *g*, Einsiedl level.

Fig. 69.—Faulting of the contact by a "Blatt." *a*, slate; *b*, limestone.

Fig. 70.—Vertical N. and S. cross-section through the Benyes mine, Rodna, Transylvania. *a*, mica-slate; *b*, andesite; *c*, limestone. Adits: *d*, Amalia; *e*, Zap Peter; *f*, Anton; *g*, Nepomuk; *h*, Teresia.

Fig. 71.—Section through the "New Lead-Mass," in Mt. Ambree, Offenbánya, Transylvania. *a*, mica-slate; *b*, andesite; *c*, limestone. Levels: *d*, Segen Gottes; *e*, Glück auf; *f*, ore-shoot.

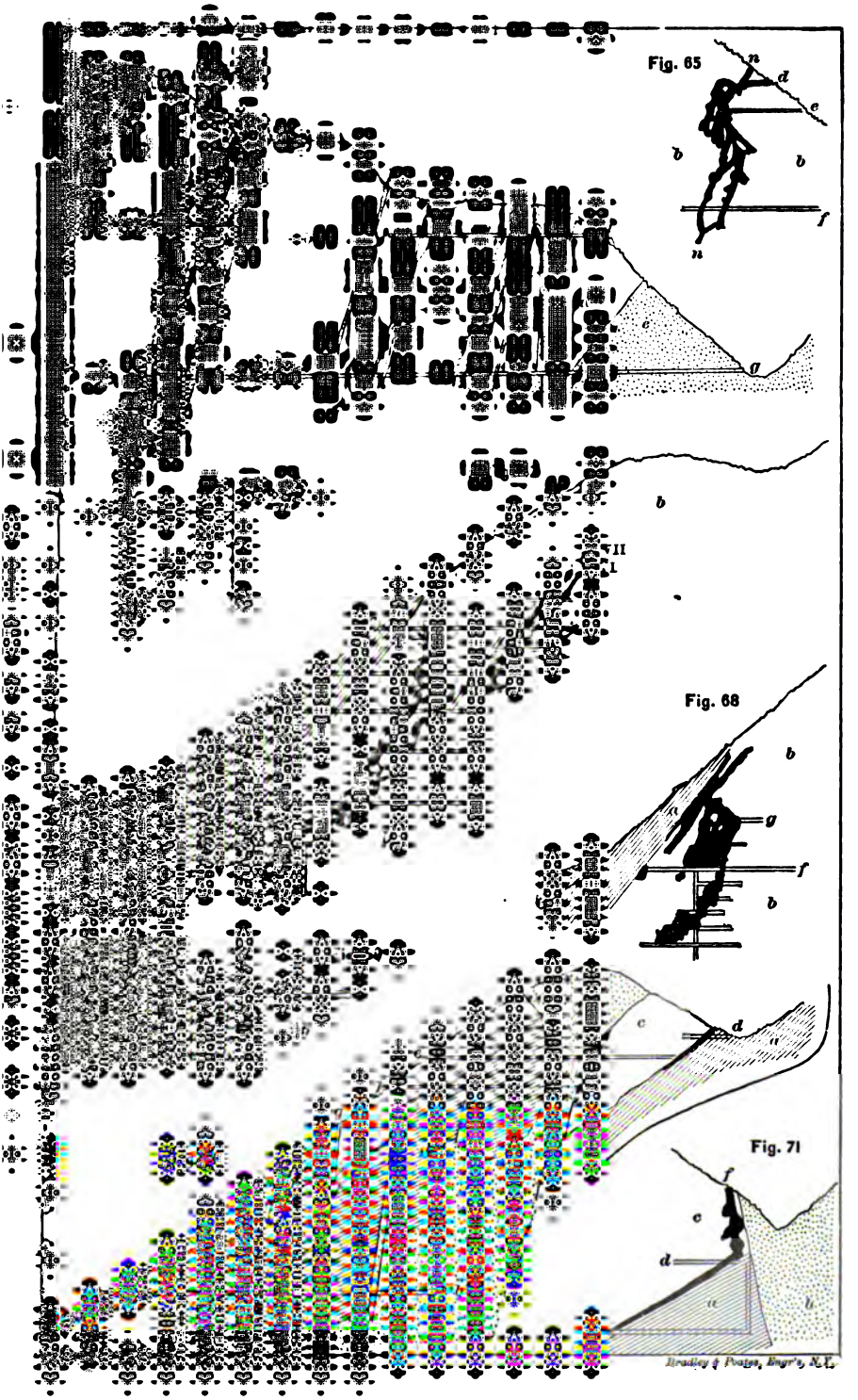
Fig. 65
n
d
e
b
b
f
n
c
g
b
II
I
Fig. 68
b
a
g
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b
c
d
Fig. 71
f
c
d
a
b
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Description of Figures.

Fig. 72.—Face of level on the *Johanniblatt*, at Raibl, where the ores occur in the country-rock.

Fig. 73.—Vertical E. and W. section through the McKean shaft, Iron Hill, Leadville, Colo. W. P., white porphyry; B. L., blue limestone; G. P., gray porphyry; W. L., white limestone; L. Q., lower quartzite; G., granite. (A. A. Blow.)

Fig. 74.—Sections from the Red Mountain district, Colo. A., andesite; P. Q., pink quartzite; L., limestone; L. Q., lower quartzite; *a*, Batavia shaft; *ab*, Jackson tunnel; *c*, adit; *oo*, ore. (G. E. Kedzie.)

Fig. 75.—Section across Longfellow Hill and Chase Creek, Clifton district, Arizona. A, Longfellow Hill; B, Chase Creek; *aa*, felsite; *b*, limestone; *c*, sandstone; *d*, porphyry; *e*, upper adit; *f*, deep adit. (A. F. Wendt.)

Fig. 76.—Ideal section at Eureka, Nevada. A, Ruby Hill; *a*, Prospect Mountain quartzite; *b*, crushed limestone; *c*, limestone; *d*, shale; *e*, stratified limestone; *f*, Secret Cañon shale; *g*, Hamburg limestone; *i*, Logan shaft; *p*, Lawton shaft. (J. S. Curtis.)

Fig. 77.—Combined section at Eureka for comparison with Fig. 76. *a*, *b*, *c*, *d*, *e*, *f*, as above; *k*, Windsail shaft; *l*, Bell shaft; *m*, Richmond shaft; *x y*, east ore-body; VII., Richmond 7th level. (J. S. Curtis.)

Fig. 78.—Sketch of face of 310 feet level. Old Telegraph mine, Utah, showing texture of the filling (altered to cerussite). *a*, hanging-wall clay; *b*, quartz; *c*, quartzite.

Fig. 79.—Section from the lead-region of Wisconsin, in the neighborhood of Dubuque, Iowa. (J. D. Whitney.)

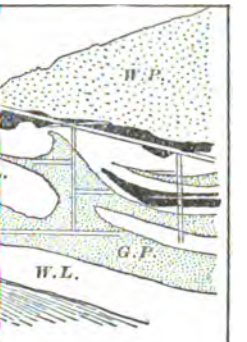


Fig. 75

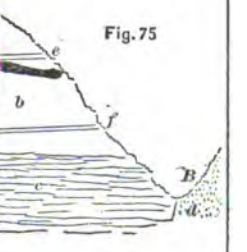


Fig. 78

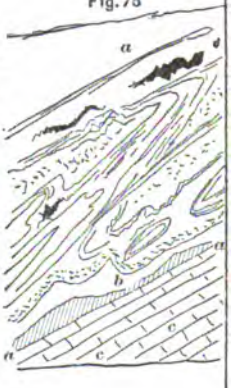
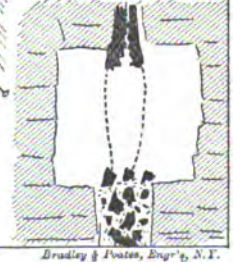


Fig. 79



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Description of Figures.

Fig. 80.—Plan of ore-deposits at Wallerfangen and St. Avold, near Saar Louis. (C. Simon.)

Fig. 81.—Cross-section of 81. H, hanging-wall; F, foot-wall.

Fig. 82.—Cross-section of the Mechernich deposits, showing irregular faulting of the *Knoten* sandstone beds.

Fig. 83.—Cross-section of the Vesuvius mine, Freihung, Bavaria. *a*, Keuper clay; *b*, variegated sandstone; *c*, ore-beds; *d*, engine-shaft.

Fig. 84.—Section of a tree-stem, replaced with galena, from Freihung.

Fig. 85. Calamine veinlets in the limestone at Raibl; *a*, limestone.

Fig. 86.—Cellular calamine of Raibl.

Fig. 87.—Section through the Laurium district, Greece; *a*, limestone; *b*, schist; *c*, Hilarion shaft.

Fig. 88.—Section through the Laurium district; *a*, limestone; *b*, schist; *d*, porphyry dikes. (A. Huot.)

Fig. 89.—Limonite-deposit in West Cumberland; *a*, millstone grist; *b*, mountain limestone; *c*, Silurian schist. Hematite in place. (J. D. Kendall).

Fig. 90.—*Bohneisenerz*-deposit of Wochein, Carniola; *a*, limestone; *b*, iron-ore. (A. v. Morlot.)

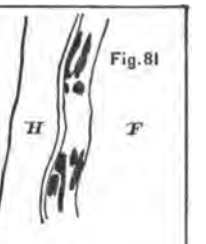

Fig. 81

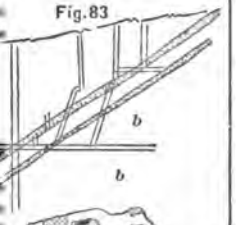

Fig. 83

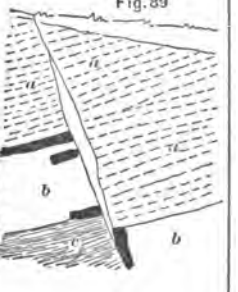

Fig. 89

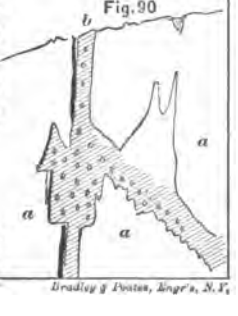

Fig. 90

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Description of Figures.

Fig. 91.—Tin-vein in Cornwall, with pseudomorphs of cassiterite after feldspar in the granite country-rock. (C. Le Neve Foster.)

Fig. 92.—Tin-vein in Cornwall, showing "capel" or altered "killas" country-rock. (C. Le Neve Foster.)

Fig. 93.—Impregnation of the granite with tin-ore at East Wheal Lovell, Cornwall. (C. Le Neve Foster.)

Fig. 94.—Specimens of ore from the Kongens mine at Rōras, Norway. (Th. Kjerulf.)

Fig. 95.—Specimen of ore from the Mug mine, Trondhjem, Norway; *a*, pyrrhotite; *b*, mica; *c*, quartz; *d*, chalcopyrite. (Th. Kjerulf.)

Fig. 96.—Polished section of ore from Åmmeberg, Sweden.

Fig. 97.—Ditto, showing leaf-silver in fissures in zinc-blende.

Fig. 98.—Section through the Copper Falls mine, Lake Superior; *a*, trap; *b*, ash-bed at depth of 80 feet; *c*, amygdaloid; *d*, sandstone at depth of 420 feet.

Fig. 99.—Nagynyerges vein at Kisbánya, Transylvania.

Fig. 100.—Section through Palæozoic detrital gold-deposit of the Black Hills; *a*, porphyry; *b*, schist; *d*, Potsdam (old contact-lines dotted); *e*, cement-mines; *ff*, placers, the one on the left in the drawing being in Deadwood gulch at Central City; the one on the right, in Blacktail gulch. (Devereux.)

Fig. 94

Fig. 95

Fig. 97

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REVIEW OF AMERICAN BLAST-FURNACE PRACTICE.

BY E. C. POTTER, CHICAGO, ILL.

(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

IT is not the purpose of this paper to enter into the minutiæ of a subject so vast, upon which volumes have already been written and volumes more might still be written, but simply to pass in review the characteristic features of that practice, which, dating from the blowing-in of the Edgar Thomson "A" furnace in 1879 and continuing down to the present day, has given to American blast-furnace operations a new significance. The blowing-in of "A" furnace marked the beginning of a new era in the science of iron-smelting, if, indeed, it was not the very birth of science as applied to this industry in the United States. American blast-furnace practice in its generic sense and world-wide significance dates from that day, and really all that is valuable, all that is remarkable or worthy of discussion, is embraced in the experiences and achievements of the past fifteen years. Back of that we find only the dead level of mediocrity, or worse, a disposition to "let well enough alone;" a general, almost universal, employment of "rule of thûmb" methods. The application of scientific principles and methods was rare and, indeed, previous to the introduction of the Bessemer process in the early seventies, science had no place in controlling the operations of the American blast-furnace. The old practice consisted mainly in dumping raw materials in at the top of the furnace and tapping out iron and slag at the bottom, for the successful consummation of which the furnace-manager directed his best energies toward keeping the furnace as free as possible from "gobbing" with, alas! but indifferent success. The burdening of the furnace was based largely on Mark Twain's receipt for "Johnny-cake," altered to suit the circumstances, viz.: a lot of ore, a lot of fuel and about a quarter of a lot of flux. The possible capacities of furnace-plants were not nearly realized. Enormous wastes were permitted, unheeded because not understood. In the use of fuel *quantum suff.* was always the rule. Increase of product was not thought of because it was not deemed wise or safe to attempt

anything beyond the rated or recorded capacity, and the furnace "seemed to be doing all it could, anyway." Generally speaking, the composition of the raw materials was but partially and imperfectly known, if known at all. A chemist, in most works, was unheard of.

The introduction of the Bessemer process was the first rude awakening of these easy-going furnacemen. They learned then, some of them for the first time, that there was such a thing as phosphorus. Sulphur was the one chemical element with which they already had some acquaintance, and their remedy for that was a full diet of fuel and lime—simple and efficacious, but how expensive they never knew. When pig-iron was selling at from $40 to $50 per ton, it did not much matter. With the recognition of phosphorus as an enemy, capable of spoiling a lot of otherwise good iron, the chemist appeared for the first time on the scene. Soon the Bessemer process introduced to the notice of the perplexed furnaceman another and most important factor, namely, silicon. In his effort to keep silicon within bounds he found sulphur asserting itself to his complete distraction. The chemist became more and more the manager's main stay in his hour of trial. Soon the chemist himself was manager and the new era had fairly dawned.

But it was not until 1879 that the features which now characterize the blast-furnace practice of this country began to be developed. In that year the first of the now world-famous Edgar Thomson furnaces —Furnace "A"—was erected and blown in. An account of this furnace and its work by its builder and manager, Mr. Julian Kennedy, has been published (*Trans.*, viii., p. 348), and need not be repeated here. This was a small furnace—66 feet high by 13 feet bosh—yet how startled was the metallurgical world when it was known that this little furnace was yielding regularly 650 tons per week! Furnaces 30 per cent. larger were at that time yielding 350 to 400 tons per week, which was considered very satisfactory. This was also one of the first furnaces in this country to use the regenerative fire-brick hot-blast stoves, which contributed in no small degree to its remarkable record. With furnace "B" of the same plant, blown in some months later, another giant stride forward was taken. Of much more ample dimensions than "A," this furnace leaped into fame with a weekly product of 1200 tons, being the first furnace in the world to produce so large an amount. Furnaces "C," "D" and "E" followed in rapid succession, each eclipsing its predecessor in output until 1400 to 1500 tons per week came to be the regular thing, and the Edgar Thomson plant became the

Mecca of furnace-managers and owners from Europe as well as America. "American rapid driving" became a much-discussed question on both sides of the Atlantic, the serious and decisive objection found by our European friends being the great waste of fuel. Of this there could be no denial. The consumption of fuel in American blast-furnaces had always been much greater than in those of Europe; and the rapid driving certainly had not decreased it. The Europeans were well content with their small outputs so long as their fuel-consumption was relatively low; yet the Americans, having once tasted the glory and profit of rapid driving, were not willing to retrograde in this particular. Thus matters stood until 1885, during which year experiments looking to better economy in fuel-consumption were instituted at the South Chicago furnaces of the North Chicago Rolling Mill Company. The previous history of these furnaces is related in a paper read before the British Iron and Steel Institute (*Journal I. and S. I.*, 1887, No. 1, p. 163), and need not be detailed here. These experiments continued through the larger part of 1885. At the beginning, matters stood as follows:

Week Ending April 11, 1885.

	Tons.	Pounds per ton of yield.
Furnace No. 5, ...	yield, 1055	coke, 2506
Furnace No. 6, ...	yield, 1013	coke, 2516
Furnace No. 7, ...	yield, 1148	coke, 2676

Month Ending April 30, 1885.

Furnace No. 5, ...	yield, 4840	coke, 2342
Furnace No. 6, ...	yield, 4920	coke, 2326
Furnace No. 7, ...	yield, 5167	coke, 2622

It is proper to say, that this was the first month of the campaign with No. 7. By the end of the year the situation was as follows:

Week Ending December 19, 1885.

	Tons.	Pounds per ton of yield.
Furnace No. 5, ...	yield, 1413	coke, 1856
Furnace No. 6, ...	yield, 1402	coke, 1898
Furnace No. 7, ...	yield, 1416	coke, 1878

Month Ending December 31, 1885.

Furnace No. 5, ...	yield, 5752	coke, 1912
Furnace No. 6, ...	yield, 5987	coke, 1911
Furnace No. 7, ...	yield, 5926	coke, 1892

And this continued to be the regular practice of these furnaces, though, by 1887, still better results had been reached:

Week Ending November 12, 1887.

	Tons.	Pounds per ton of yield.
Furnace No. 5, ...	yield, 1449	coke, 1776
Furnace No. 6, ...	yield, 1394	coke, 1759
Furnace No. 7, ...	yield, 1413	coke, 1800
Furnace No. 8, ...	yield, 1255	coke, 1867

Month Ending November 30, 1887.

Furnace No. 5, ...	yield, 6258	coke, 1769
Furnace No. 6, ...	yield, 6040	coke, 1801
Furnace No. 7, ...	yield, 5855	coke, 1862
Furnace No. 8, ...	yield, 5377	coke, 1902
	Total, 23,530	Average, 1834

Furnace No. 8 was then in the last month of its campaign. These four furnaces yielded, during the last six months of 1887, 133,427 tons of iron, with an average coke-consumption of 1919 pounds per ton of iron produced.

It has thus been shown, that rapid driving and low fuel are not incompatible, and the "American" practice has at last been thought worthy of serious consideration by our European friends. But, progress is still the order of the day with us. Edgar Thomson having developed the practice of rapid driving, and South Chicago having added thereto the possibilities of fuel economy, the Edgar Thomson furnaces, under the masterly management of Mr. James Gayley, again claim the attention of the metallurgical world by still more marvellous achievements in the way of large outputs, low fuel-consumption, and enormous increase in the life of the furnace-lining. The last is the newest problem in furnace-practice, to which furnace-managers have been devoting their best efforts, and in which Mr. Gayley has been signally successful. One of his furnaces, which has just completed thirty-seven months of its present blast (April, 1893), has made in that time 370,000 tons of metal, and is now running at the rate of 11,000 tons per month. There is no reasonable doubt that this furnace will make over 400,000 tons on this lining. Mr. Gayley has records of 623 tons in a single day, 3203 tons in a week, and 12,800 tons in a month, from a single furnace. A record which compares with this, taking into consideration the difference in the size of the furnaces, is that of the Illinois Steel

Company's Milwaukee No. 2 furnace. This furnace has 8150 cubic feet capacity, and was running on foundry-iron. The record is as follows:

Largest day, March 12, 1892, . . .	225 tons of 2268 pounds.
Largest week, ...	1430 tons of 2268 pounds.
Largest month, 31 days, ...	6127 tons of 2268 pounds.
Average per day, ...	197.6 tons of 2268 pounds.

Fuel consumption, best week, 1824 pounds coke.
Fuel consumption, best month, 1925 pounds coke.
Grade of product, foundry iron. 75 per cent. No. 1.
Average sulphur for month, .032 per cent.

This record reflects the highest credit upon the manager, Mr. T. W. Robinson. The yield for this month is at the rate of 2.42 tons per 100 cubic feet capacity per day, which, I believe, has not yet been equalled. In 1879, the same furnace was making regularly 350 tons per week with a fuel-consumption of 3500 pounds of coke per ton product! The alterations made in the furnace-plant since that time consist in the substitution of fire-brick, regenerative hot-blast stoves for the old iron-pipe stoves, an additional blowing-engine, altered lines, and a *new manager*. It is interesting to compare this record with that of Edgar Thomson furnace "A" of 1879 previously cited. The difference in the size of the furnaces is not so great—furnace "A" having 6400 cubic feet capacity—but the comparison serves to indicate sharply the progress made in thirteen years. The records of these two furnaces stand as landmarks in the history of American blast-furnace practice, the performance of "A" furnace in 1879 being as remarkable an advance over contemporaneous practice as that of the Milwaukee furnace of 1892 is over that of furnace "A."

As if to further tax the patience and abilities of furnace-managers there came into use almost simultaneously with the new régime the method, strange to America at least, of taking the pig-iron direct from the furnaces in a molten condition to the Bessemer converters, known in this country as "the direct-metal process." The limitations which this procedure places upon the operations of the blast-furnace are extraordinary, confining the furnace-manager to very narrow fluctuations in the chemical composition of the product as well as the temperature of the furnace itself. In fact, after many years of faithful and well-directed effort, it has been deemed impracticable to depend wholly upon the steady maintenance of uniformity in the furnace-operations; and an apparatus has been de-

vised to equalize the variations of both chemical composition and temperature of the furnace-product. This apparatus, known as a "mixer," was devised by the late Captain W. R. Jones of the Edgar Thomson Works, and at once filled a "long-felt want," besides removing from the already over-tried furnace-manager a very considerable burden. It will be interesting, however, to note with what degree of success the furnace-manager met the conditions required before the advent of the mixer; and to this end I give below the only data at hand bearing on this point. These consist of the daily averages of silicon and sulphur analyses of the product of the four South Chicago furnaces for certain typical periods. These furnaces were the first in the United States to be operated wholly and regularly on the direct-metal process, and were so operated for ten years before a mixer was introduced. The results here given I consider remarkable in their uniformity; and the success of these furnaces and of the entire South Chicago Works as well as the permanent establishment of the direct-metal process in this country, is due largely to the very able and intelligent management of Mr. Michael Smith, who had charge of these furnaces for the ten years referred to. These daily analysis-records have been kept from the beginning of the low-fuel experiments in 1885 to the present day; and the examples here given are not selected for their special excellence, as they can be many times duplicated, but to illustrate certain features of the practice which were operative at the time.

Table I., for the month of May, 1886, illustrates an effort to operate the furnaces so as to produce a pig-iron as low as possible in silicon, to facilitate the blowing in the Bessemer department, at the same time keeping the sulphur within reasonable bounds. The fuel consumption in this case was a secondary consideration. The furnace-records for this month are as follows:

	Tons.	Pounds per ton of yield.
Furnace No. 5, ...	yield, 5250	coke, 1961
Furnace No. 6, ...	yield, 5263	coke, 1968
Furnace No. 7, ...	yield, 5599	coke, 1918
Furnace No. 8, ...	yield, 5364	coke, 1891

The higher lime-burden necessary to keep the sulphur down in the very low-silicon pig explains the higher fuel-consumption.

Tables II. and III. illustrate an effort for the largest tonnage and lowest fuel-consumption possible. With the furnaces going at their best rate, the fluctuations in silicon are slight and the percentage

TABLE I.—*Daily Averages of Silicon and Sulphur in Pig-Iron, South Chicago Furnaces, May*, 1886.

Date.	No. 5.		No. 6.		No. 7.		No. 8.	
May	Si.	S.	Si.	S.	Si.	S.	Si.	S.
1	.95	.054	1.24	.050	1.81	.016	1.09	.049
2	1.82	.030	1.52	.031	1.36	.030	1.61	.022
3	.91	.063	1.14	.032	1.19	.031	1.04	.027
4	.91	.079	.80	.070	1.24	.045	1.00	.037
5	1.56	.065	1.00	.032	1.50	.039	1.14	.038
6	1.34	.048	1 66	.016	1.24	.050	1.15	.054
7	1.25	.101	1.17	.046	1.20	.091	.82	.118
8	1.34	.082	1.18	.050	1.33	.104	1.38	.060
9	1.18	.123	.95	.092	1 32	.057	.61	.103
10	1.23	.065	1.36	.032	1.31	.050	1 00	.062
11	1.10	.048	1.04	.039	1.06	.064	1.54	.019
12	1.07	.056	.90	.058	.94	.053	.65	.059
13	1.40	.073	1.39	.035	.89	.123	.34	.159
14	1.37	.051	1.35	.029	1.18	.035	1.20	.066
15	1.28	.040	1.28	.038	1.71	.020	1.31	.035
16	1.74	.074	2.00	.019	2.11	.026	1.52	.026
17	1.74	.050	1.66	.031	1.40	.057	1.75	.021
18	1.29	.048	1.28	.042	1.16	.074	1.76	.021
19	1.18	.065	1.48	.035	1.03	.081	1.40	.027
20	1.56	.070	1.18	.050	1.07	.064	1.26	.031
21	1.03	.056	.87	.052	1.26	.038	1.04	.030
22	1.20	.036	.84	.047	.98	.064	1.38	.017
23	.76	.082	.71	.061	.84	.122	1.20	.086
24	1.20	.062	1.38	.025	85	.149	.89	.041
25	1.23	.083	1.10	.044	.96	.099	1.38	.038
26	1.27	.080	1.32	.035	.86	.113	1.28	.048
27	1.73	.080	1.23	.049	1.54	.038	1.43	.047
28	1.98	.046	1.37	.057	1.46	.052	1.58	.046
29	1.46	.073	1.98	.030	1 31	.074	1.90	.027
30	2.06	.073	1.73	.021	1 77	.034	1.86	.035
31	2.04	.038	1.86	.071	1.43	.035	1.66	.044
Aver.,	1.36	.064	1.29	.042	1.27	.063	1.26	.048

moderate. The steadiness of the sulphur is remarkable; in fact, the record presented by Furnace No. 8 I have never seen equalled. These tables show a continuous sixty days' run, and the records are as follows:

Month of October, 1887.

	Tons.	Pounds per ton of yield.
Furnace No. 5, ...	yield, 6343	coke, 1798
Furnace No. 6, ...	yield, 5995	coke, 1848
Furnace No. 7, ...	yield, 5753	coke, 1910
Furnace No. 8, ...	yield, 5598	coke, 1871
	Total, 23,689	Average, 1857

TABLE II.—*Daily Averages of Silicon and Sulphur in Pig-Iron, South Chicago Furnaces, October*, 1887.

Date.	No. 5.		No. 6.		No. 7.		No. 8.	
October	Si.	S.	Si.	S.	Si.	S.	Si.	S.
1	1.58	.100	1.28	.083	2.26	.025	2 00	.031
2	1.98	.063	1.21	.056	2.51	.016	1.21	.031
3	2.15	.073	2.95	.021	1.65	.059	2.40	.024
4	1.98	.086	1.60	.079	1.83	.098	2.21	.036
5	1.94	.045	2.16	.036	2.33	.015	1.81	.053
6	1.46	.071	2.13	.026	1.99	.024	1.77	.054
7	1.50	.044	.80	.199	1.07	.140	1.71	.024
8	1.70	.044	1.72	.078	1.99	.039	2.00	.029
9	1.64	.042	1.69	.042	2.36	.020	1.66	.029
10	1.92	.023	2 06	.022	2.07	.047	2 49	.026
11	1.63	.051	1.33	.081	2.31	.055	1.54	.075
12	1.92	.054	1.56	.059	2.04	.041	2.10	.036
13	2.22	.028	1.99	.041	1.77	.063	1.79	.029
14	1.69	.070	1.48	.041	2 14	.032	1.61	.044
15	2.02	.048	1.62	.042	2 08	.056	2.18	.022
16	2.11	.027	1.57	.056	1.63	.074	1.50	.057
17	1.38	.064	1.62	.068	1.43	.062	2.23	.044
18	1.77	.043	2.13	.048	2.33	.045	1.67	.052
19	1.77	.027	1 00	.103	1.87	.064	1.85	.032
20	1.51	.043	1.30	.059	1.62	.093	1.37	.060
21	1.72	.022	1 68	.024	2.02	.039	1.71	.032
22	1.94	.032	1.72	.032	2.18	.034	1.82	.022
23	1.48	.048	1.66	.054	2 13	.045	2 25	.018
24	2.40	.029	1.90	.046	1.85	.052	2.07	.040
25	1.60	.045	1.55	.042	1.81	.082	1.53	.120
26	1.45	.042	1.64	.029	1.88	.073	2.07	.047
27	1.14	.101	1.55	.028	1.83	.071	1.88	.053
28	1.84	.038	1.24	.033	1.75	.062	1.97	.053
29	1.76	.035	1.26	.066	2.31	.048	1.82	.065
30	1.84	.041	1.12	.156	2.71	.039	2.51	.030
31	1.40	.054	1.98	·032	1.77	.086	2.23	.039
Aver.,	1.76	.050	1.63	.057	1.98	.055	1.90	.042

Month of November, 1887.

	Tons.	Pounds per ton of yield.
Furnace No. 5, ...	yield, 6258	coke, 1769
Furnace No. 6, ...	yield, 6040	coke, 1801
Furnace No. 7, ...	yield, 5855	coke, 1862
Furnace No. 8, ...	yield, 5377	coke, 1902
	Total, 23,530	Average, 1834

These were the last two months of the campaign with furnace No. 8. The average fuel-consumption for the entire blast of this furnace was 1979 pounds.

TABLE III.—*Daily Averages of Silicon and Sulphur in Pig-Iron, South Chicago Furnaces, November*, 1887.

Date.	No. 5.		No. 6.		No. 7.		No. 8.	
Nov'r.	Si.	S.	Si.	S.	Si.	S.	Si.	S.
1	1 51	.054	1.70	.030	1.95	.043	1.83	.040
2	1.49	.066	1.19	.053	1.86	.044	2.14	.039
3	1.52	.030	1.43	.035	1.97	.035	2.09	.036
4	1 32	.046	1.54	.028	1.54	.030	1.98	.056
5	2 15	.034	1.72	.033	1.56	.036	1.98	.045
6	1.50	.031	1.09	.054	2.25	.032	1 99	.066
7	1.18	.079	.82	.104	2.23	.032	2.23	.039
8	1.76	.029	1.73	.029	1.76	.065	1.96	.049
9	1.28	.045	1.42	.044	1.50	.072	1.92	.034
10	1.20	.046	1.43	.056	1.80	.039	1.80	.047
11	1.15	.091	1.25	.057	1.70	.052	1.81	.048
12	1.66	.047	1.24	.099	1 59	.066	1.72	.047
13	1.34	.046	1.60	.040	1.71	.088	2.15	.035
14	1.87	.043	1.12	.082	1.64	.076	1 98	.032
15	1.38	.065	1.28	.097	1.72	.075	1.94	.031
16	1.46	.048	1 24	.129	1.50	.087	1.92	.035
17	1 64	090	1.32	.097	1.98	.077	1 92	.030
18	1.60	.078	1.66	.072	1.93	.074	2 03	.043
19	1.58	.070	1.37	.077	1 82	.115	2.43	.027
20	1.47	.094	1.66	.052	1.98	.093	2.03	.034
21	1 76	.051	1.76	.041	1.98	.076	1.52	.034
22	1.43	.039	1.85	.056	1 57	.070	1 98	.029
23	1.24	.082	2.00	.020	1.98	.053	2 06	.056
24	1.57	.080	1.51	.056	1.52	.074	1.79	.057
25	1.61	.082	1.78	.041	2.38	.031	2.23	.042
26	2.14	.040	2.47	.028	2 06	.049	2.36	.036
27	2.00	.055	2.34	.033	2.20	.055	2.13	.043
28	1.42	.138	1.68	.067	2.64	.030	2.68	.026
29	1.54	.120	1.71	.076	2 55	.043	2.64	.017
30	2.18	.054	1.71	.076	2.32	.047	2.37	.064
Aver.,	1.57	.065	1 56	.059	1.91	.059	2.06	.041

I would not have it thought that I have so far confined myself to the operations of the Edgar Thomson and South Chicago furnaces because these are the only furnaces in this country that are doing creditable work. It is true that a large share of the features of our modern furnace-practice was developed at these establishments, as one might reasonably expect. The magnitude of these plants, their ample equipment and resources, and above all, the raw materials at their command, have made it possible for them to lead in the exploration into new and unknown regions. It will be found, also, that the furnaces having the best records are those that use for raw material the ores of Lake Superior and Connellsville coke, a combination which, for excellence in smelting, cannot be duplicated in

the known world. This, however, does not preclude the ability of other furnaces to make excellent showings, due cognizance being had of the various conditions under which they are working. In no country on the globe does the smelting of iron present such manifold and varied conditions as in America. For fuels we have charcoal, coke and anthracite, the latter being peculiar to this country. Our ores embrace the wide range from brown hematites yielding 30 per cent. of iron to the rich magnetites and specular ores yielding 68 to 70 per cent. of iron. In the Southern States, where, ten years ago, the production of pig-iron was insignificant, we find a series of blast-furnace plants which, in excellence of arrangement, construction and equipment are finer than can be found in any other section of this country of equal extent and producing capacity, taken as a whole. These furnace-plants, working with probably the poorest raw material in both ore and fuel that the country affords, are producing the cheapest iron in this country if not in the world, and are invading all sections of America with their product. The most famous record-breaking furnaces in the country have learned to recognize in these Southerners competitors worthy of their most strenuous and tireless exertions.

In anthracite-practice, which concededly presents more difficult problems to the furnace-manager than any other, the performances of the Warwick, Durham, and Franklin furnaces, and the uniform excellence of the work of the Thomas furnaces, are evidence that the coke-furnaces do not hold all the honors.

The charcoal-furnaces occupy a unique position. Generally speaking, they are not brought into sharp competition with the coke- or anthracite-furnaces. Their product is usually of a special character and supplies a special market. By reason of the nature and source of their fuel-supply, these furnaces are usually situated remote from the centers of industry, and are to a large degree lost to public view. The plants are, for the most part, of rather antiquated type and limited capacity.

It is interesting, therefore, to note the performance of a recent charcoal-furnace, modern in every particular and in size considerably larger than any other charcoal-furnace extant. The Hinkle furnace at Ashland, Wis., was blown in for its first blast in 1888. The plant is entirely modern in its arrangement and equipment. The furnace is 60 feet in height and 12 feet in bosh-diameter, with a rated capacity of 100 tons per day. A single week's run, as published in the *Iron Age*, amounted to 1009 gross tons of iron, on a

fuel-consumption of 80 bushels of charcoal per ton of product, the bushel being rated at 22 pounds. The performance of this furnace has clearly demonstrated, what seemed to be a matter of doubt before, that furnaces of considerable size and modern equipment can be operated with charcoal as fuel and produce results as creditable, whether commercially or metallurgically considered, as any of the coke-furnaces. In short, we have seen that any furnace-plant, no matter what its conditions, will respond at once to careful and intelligent management, and the whole iron-smelting industry of America has thus been raised to a vastly superior condition as compared with its condition previous to 1879.

Uninterrupted operation is the *sine qua non* of the attainment of notable furnace-records, and the development of modern American furnace-plants has been made with this object steadily in view. Hence, a characteristic feature of these plants is the duplication of parts, with the view of forestalling as far as possible all contingencies and accidents which would interrupt the continuous operation of the furnace. This feature is made more manifest by comparison with our own older plants or with those of Europe. It is not uncommon at the present day to see in Europe, especially in England, whole furnace-plants, often embracing half a dozen stacks, blown by a single gigantic engine, and the fume from all the boilers and stoves conducted off by a single mammoth chimney, both engine and chimney standing as monuments to human skill and daring. The larger they are, or the greater the number of furnaces depending upon their united efforts, the greater the credit redounding to their designer and builder. But if anything happened to either chimney or engine, an entire furnace-plant would be placed *hors de combat*. The chimney may seem to be a tolerably reliable part of the apparatus, yet it has happened within the personal experience of the writer that the lining of a large chimney appertaining to the boilers of four furnaces fell in without a moment's warning, so that in the twinkling of an eye four large furnaces were deprived of power, and remained so for ten long dismal days. Since this episode I have lost confidence in monumental chimneys. In modern American furnace-plants we find each stack built and operated separately and distinctly from its sisters. Even the custom of working furnaces in pairs from the same hoist is no longer considered the best practice, because an accident to the hoist would affect two stacks instead of one. Instead of the single gigantic engine we find two or even three independent engines provided for each stack; and in plants of two or more stacks the air-receivers

are so connected by a system of valves that any one engine in the house may be applied to any one of the stacks. Each boiler, or at least each pair of boilers, is provided with a chimney, so that here almost complete independence exists, the only part of the apparatus common to all being the main gas-flue. Even in case of failure of this, it is possible to fire each boiler with fuel independently. While the majority of the hot-blast stoves now in use are so constructed that a common chimney is necessary, yet there are a number of the new types of stove that are provided each with its own chimney,—a feature, in my estimation, of great value, as it renders each of the stoves attached to a furnace entirely independent. A furnace thus equipped could suffer the temporary loss of an engine, a stove, and two or three boilers without interruption in its operation.

The external appliances being thus provided for, the maintenance and prolongation of the life of the interior of the furnace—the lining—has in recent years received the earnest attention of furnace managers. The use of water-cooled plates inserted in the lining and about the wall of the furnace illustrates the ingenuity and courage of the modern furnace-engineer; for the juxtaposition of cold water and molten iron separated by a film of metal a fraction of an inch in thickness is, at first glance, rather startling. By their aid the life of the lining has been materially prolonged and, more valuable still, the lines of the boshes are steadily preserved at something near their original contour, thus greatly assisting in maintaining uniform performance of furnace operations. The performance of the Edgar Thomson furnaces, cited above, is a remarkable instance of this.

In the daily operation of the furnace, no detail is considered too insignificant for careful study and improvement, since any one of these details may prove to be a point of vantage over a competitor. In this way, the smelting of iron in this country has been perfected. The inspiration of such progress has been an emulation peculiarly American. In this country, with few exceptions, all works are open to visitors, native and foreign alike. The interchange of ideas and experiences between managers is free and unreserved. The better practice of one plant serves as a stimulus to others. To this friendly rivalry the present excellence of American furnace-practice is largely due. Great progress is well-nigh impossible where every works is closely fenced and guarded, and where it is deemed high treason to reveal the least of the "secrets" of the process. American iron and steel works depend, not upon secrecy but upon individual ability, for success and progress.

With the advent of the Bessemer process, the manufacture of steel became a most attractive field for our metallurgical and mechanical engineers. The marvellous evolution of this process and its associate industries demanded and developed brilliant minds. The process itself, attractive even to laymen with its brilliant pyrotechnics, its magical rapidity, and its ponderous and intricate machinery required for the manufacture of steel and its subsequent manipulation, completely over-shadowed the prosaic operations of the blast-furnace, and our young engineers and technical students sought the steel works as the only field worthy their attention in the metallurgy of iron. With the blowing-in of Edgar Thomson "A" the possibilities of the blast-furnace began to be made manifest. It was seen that laurels were to be won here; and technical students began to study iron-smelting, with the result that the economical production of pig-iron was found to involve quite as many scientific problems as the production of steel. Moreover, by reason of the high tension at which American furnaces are operated, they have become in our hands apparatus of a much more sensitive and nicely adjusted character; and the mind that directs them must be the more keen, alert and ingenious than was required when furnaces were driven at a more sober pace. Thus we find the larger number of our furnaces now in the hands of bright and talented men, whose intelligence and energy wrought the splendid evolution of American blast-furnace practice.

SULPHUR IN CAST-IRON.

BY W. J. KEEP, DETROIT, MICH.

(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

ALMOST without exception, writers on the subject say that sulphur in cast-iron will cause it to be white, and is in every way injurious. All founders believe that a small amount of sulphur in the fuel will work great damage, and that if any castings crack, or if anything out of the general run occurs, it may be charged to sulphur in the fuel. Fuel rarely contains more than 1 per cent. of sulphur, and if this can produce so marked an effect, one would suppose it an easy matter to introduce sulphur into cast-iron, so as to produce castings containing different desired percentages of sulphur. We have be-

lieved all that has been said against sulphur, and for six years have tried, in every way we could think of, to prove its evil tendency. Our lack of success led us to correspond with those who had had experience with sulphurous iron-ores. Their replies, without exception, were that only a very small percentage of sulphur could be made to remain in carbonized iron, and that it was very difficult, if not impossible, to introduce sulphur into gray cast-iron or into any carbonized iron. One person writes that sulphur will not amalgamate with iron saturated with carbon.

The conclusion finally reached was, that percentages of sulphur that could be retained by gray cast-iron cannot materially injure the iron except through the increase of shrinkage. Again, the testimony is, that most of the sulphur contained in the pig-iron is lost in remelting; and we think it would be impossible for carbonized iron to absorb any damaging amount of sulphur from the fuel. The higher the carbon, or the higher the silicon, the smaller will be the influence exerted by sulphur. In wrought-iron, containing practically no carbon or silicon, a small amount of sulphur is said to do great harm, and such iron will take up large quantities of sulphur.

In steel, containing less than 1 per cent. of carbon and practically no silicon, it is stated that a few hundredths of 1 per cent. of sulphur is a decided injury. As carbon increases to saturation, as in white cast-iron, not more than half of 1 per cent. of sulphur can be retained; and as silicon increases, turning the carbon into graphite, it is still more difficult to find sulphur in the iron, and such iron will not absorb it from the outside.

The influence of sulphur on all cast-iron is to drive out carbon and silicon and to increase chill, to increase shrinkage, and as a general thing to decrease strength; but if in practice sulphur will not enter such iron, we shall not have any cause to fear this tendency.

In every-day work, however, we do find at times that iron which was gray when put into the cupola comes out white, with increased shrinkage and chill, and often with decreased strength. This is caused by decreased silicon and can be remedied by an increase of silicon.

We will now give in detail a description of various tests which have led us to the foregoing conclusions, showing that whether the results which have always been ascribed to sulphur, are produced by some other cause, or directly by the sulphur in the fuel, they are not more to be feared than many other accidents of foundry-running.

They do not indicate that the iron has taken up sulphur to a damaging extent, and the evil can be prevented, or can be overcome next day, by adding enough silicon-iron to replace the silicon that has been driven out.

We made four crude tests,* melting iron of uniform composition in a crucible, and adding brimstone by means of tongs, and found:

Series I.

Test No.	Mixture.	Dead-load strength.	Shrinkage.
41	With no sulphur.	411	.120
48	With sulphur.	432	.160
47	"	358	.176
46	"	263	.207

By three crude tests, melting the same iron as above in a crucible, and adding fluorspar free from galena, and to other crucibles adding almost pure galena (containing over 14 per cent. sulphur) we obtained:

Series II.

Test No.	Mixture.	Dead-load strength.	Shrinkage.
51	With good fluorspar.	367	.137
55	With galena.	260	.165
56	"	383	.170

To iron from a cupola, of substantially the same composition as above, we added, in one ladle, iron pyrites (containing 39.88 per cent. sulphur); in another, "blue billy" (with 9.15 per cent.); in another, selected spots in coke supposed to be rich in sulphur; in another, the purest coke that we could select; and in still another, iron-ore of substantially the same composition as that in the pyrites

* All tests are made by the system described as "Keep's Test for Cast-Iron" in the *American Machinist*, January 5, 12 and 19, and February 9, 1893, and in a pamphlet by the writer. The square test-bars are $\frac{1}{2} \times \frac{1}{2} \times 12$ inches, and the flat bars $\frac{1}{10} \times 1 \times 12$ inches in size. "Strength" is the actual strength of a $\frac{1}{2}$-inch square bar, broken transversely. All results here reported are averages of at least three bars. Shrinkage is given in inches per foot; chill and deflection are in inches, actual measure.

and "blue billy," only with no sulphur. Each of these materials was ground to a fine powder, and a small foundry ladle was lined with 1 pound of each, and into each ladle 15 pounds of iron was poured from the cupola. The result was:

Series III.

Test No.	Mixture.	Strength.		Dead-load deflection.	Shrinkage.	Chill.
		Dead load.	Impact.			
608	Iron alone.	342	271	.18	.151	.15
603	Clear coke.	332	322	.18	.154	.10
604	Sulph'ry coke	346	271	.18	.153	.10
605	Iron-ore.	380	345	.19	.159	.13
606	"Blue Billy."	274	119	.08	.208	white.
607	Iron pyrites.	255	169	.07	.194	white.

In this case the iron alone showed an unusually high shrinkage and chill, for which there was no apparent reason.

All the ladles were freshly lined and had never had iron caught in them before. To find whether this would influence the iron, we freshly lined three ladles. In one of these iron was caught, and the ladle was then allowed to become cold. Another was used continuously, and the third not at all, prior to the test. We poured from each a set of bars with the following results:

Series IV.

Test No.		Dead-load Strength.	Dead-load deflection.	Shrinkage.	Chill.
624	Hot dried ladle.	335	.18	.143	.07
623	Cold "	386	.20	.151	.04
622	Green fresh ladle.	369	.19	.156	.06

This series shows that conditions often overlooked may influence castings more than chemical constitution. The iron in all the ladles was of exactly the same composition, for it was caught in a large ladle and at once poured into the small ladles.

We next endeavored to make a high-sulphur pig-iron, and melted 25 pounds of F[L]M gray iron* in a crucible, and fed slowly 8 pounds

* A Swedish gray charcoal pig-iron containing 1.249 silicon and 0.187 manganese.

of brimstone, keeping it as closely covered as possible. The operation occupied about two hours, and when completed there was at the bottom about 5 pounds of silver-white iron, covered with a very rich sulphide of iron.

This white iron showed, by analysis, 0.58 sulphur, which was conclusive proof that we could not make artificially a carbonized iron rich alone in sulphur.

Messrs. Weston and Smith, in Dr. Percy's laboratory, found that it was difficult in any case to cause cast-iron to take up sulphur, and they do not say that it turns the iron white. With our knowledge of the action of silicon, their experiments prove rather the reverse.

We made a series of tests with $F^{L}M$ gray pig-iron, adding brimstone to the melted metal, by providing a wooden cover with a wooden plug, in the lower end of which was a hole to receive the sulphur. When the iron was melted this was placed on the crucible and a heavy brick was laid on it to hold it down. This carried the sulphur to the bottom of the crucible under the melted iron, and as the brimstone melted it boiled up through the metal, but was held in by the charred cover. We remelted this series, and we give the results of the original in heavy figures and of the remelt-series in light figures side by side.

Series V.

Test No.	Mixture.	Strength.		Dead Load Deflect'n.	Shrinkage.		Chill.
		Dead Load.	Impact.		Square Bar.	Flat Bar.	
253	$F^{L}M$ and 0.00S.	.397 .413	.305 .333	.23 .21	.166 .168	.221 .226	.50 .60
265	" " 0.10S.	378 .396	.322 .367	.23 .23	.169 .178	.225 .225	50 .70
266	" " 0.30S.	.395 .397	.384 .368	.26 .25	.172 .181	.231 .231	.65 .70
267	" " 0 50S.	.381 .385	.333 .384	.22 .25	.179 .186	.219 .212	.70 .70
268	" " 0.80S.	.322 .369	.209 .330	.17 .23	.193 .193	.242 .223	.55 .60
269	" " 1.00S.	.345 .336	.362 .322	.22 .21	.192 .193	.228 .222	.50 .70
270	" " 2.00S.	.374 .341	.351 .271	.26 .18	.193 .194	.237 .220	.70 .40

The amount of brimstone necessary to produce so great a percentage of sulphur required, towards the last, two or three separate additions, and consequently the burning of two or three hollow wooden plugs in the metal. The same metal as the first member of the

gave the following,
the same is shown

	RINKAGE.		Chill.	
	Flat bar.			
86	.179	.250	0.40	.60

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crease of sulphur, the
crease remains con-
nkage of the remelt
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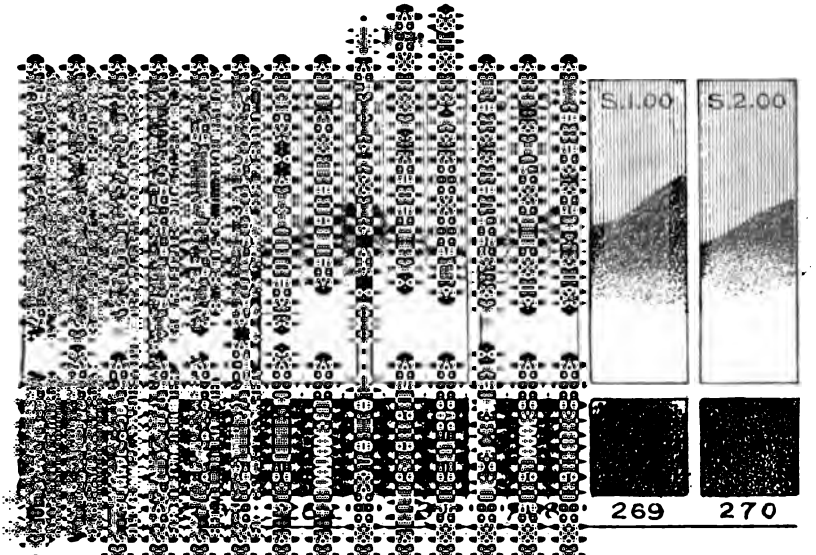


t plan. We intro-
As the sulphide

would not give up its sulphur when remelted, it formed a compound of carbonized iron and sulphide of iron. The sulphide was only in the iron a very few moments before it was put in the moulds, and therefore most of the sulphur is probably in the test-bars. We made a number of series in this way.

In ordinary foundry-practice this union would not occur, but this is the only way to cause a larger percentage of sulphur to stay in carbonized iron. The first sulphide that we used contained 25 per cent. of sulphur and 75 per cent. of pure iron. It has a shrinkage, when cast alone, of square bar .107 and thin bar .125. This sulphide and the materials used in Series III. were analyzed by Mr. A. J. Morse, of Detroit. Enough sulphide was placed in a foundry-ladle to give the desired percentage of sulphur to the castings. Enough 14.77-per cent. ferro-silicon was added to keep the silicon the same as in the cupola iron, which was about 2.5 per cent. Enough scrap of the same composition was also added to make the cooling effect the same in each ladle. The iron was caught from the cupola in a large ladle and at once divided among the small ladles. The materials added were cemented to the bottom of the ladle with fire-clay. As the added portions melted, they came to the top through the molten iron and remained there. The bars poured last from a ladle showed that more and more of the sulphide was absorbed as more time was given. The test gave the following results:

Series VII.

Test No.	Mixture.	Strength.		Dead-load deflection.	Shrinkage	Chill.
		Dead load.	Impact.		Square bar.	
625	Cupola iron, 0.00 S.	397	.....	.21	.151	.04
626	" .10 S.	422	299	.21	.152	.03
627	" .30 S.	410	352	.21	.152	.06
628	" .50 S.	400	339	.21	.150	.03
629	" .80 S.	385	307	.19	.157	.05
630	" 1.00 S.	340	271	.19	.165	.08

In the 0.80-per cent. set of bars, the first bar had a shrinkage of .153 and the last .165. In the 1.00-per cent. bars, the shrinkage of the bars was .153, .169, .168, .175, and .174, showing that sulphide was absorbed as time was given, or else that the iron highest in sul-

phide did not run out first. The influence of cooling in the ladle with no sulphide present produces a contrary effect, as is shown, for example, in the following four sets. The first bar was poured when the iron was first caught; the second when the iron was half cooled down; and the third when the iron would just fill the mould.

Series VIII.

	Test No.	Dead-load Strength.			Shrinkage.		
		Very hot.	Partly cooled.	Would just run.	Very hot.	Partly cooled.	Would just run.
No Sulphur.	22	366	424	418	.156	.157	.142
	23	427	456	478	.120	.128	.121
	24	392	427	450	.151	.148	.135
	25	441	450	473	.154	.154	.151
	26	413	.....	427	.157	.162	.170

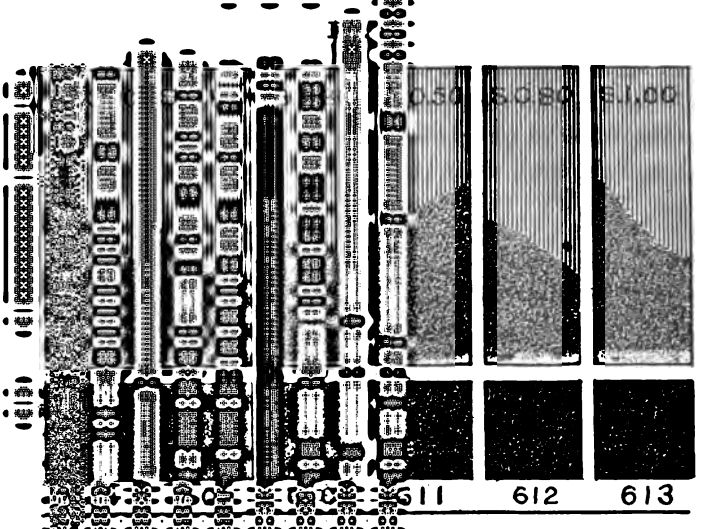
Series IX. is exactly like the last sulphide series (VII.) except that the additions were pounded fine and were thrown into the ladle loose, just before the iron was poured in.

In this series the sulphide was melted more quickly and formed a more perfect alloy, though a considerable amount floated on top. The grain and chill are shown in Fig. 2.

Series IX.

Test No.	Mixture.	Strength.		Dead-load deflection.	Shrinkage	Chill.
		Dead load.	Impact.		Square bars	
614	Cupola iron and 0.00 S.	392	299	.21	.144	.01
609	" .10 S.	395	282	.19	.144	.04
610	" .30 S.	365	254	.20	.161	.03
611	" .50 S.	382	237	.19	.173	.05
612	" .80 S.	348	212	.17	.178	.10
613	" 1.00 S	312	225	.16	.177	.10

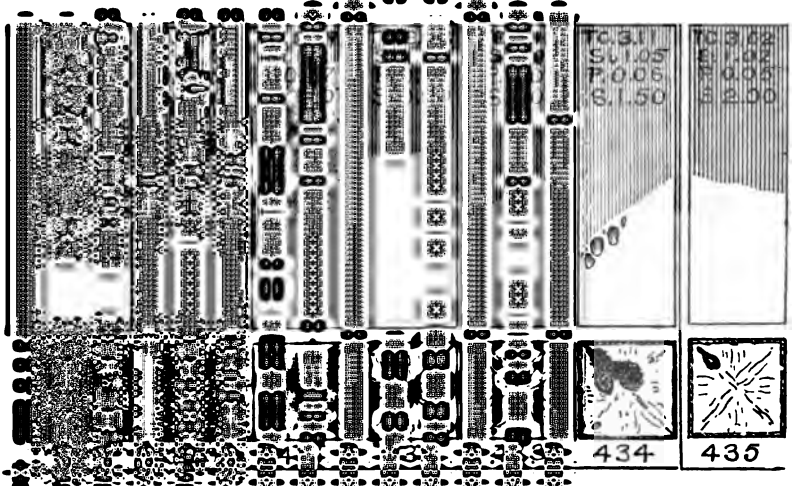
Some years ago we made in a crucible a series of test-bars using F[L]M gray pig-iron (1.25 silicon and 3.50 carbon) and added a sulphide of iron containing 22 per cent. of sulphur, which was made for this purpose and analyzed by Harry S. Fleming. This, unlike



dded to keep the silicon uni- of iron sulphide both silicon ave the following record:

	Shrinkage.		Chill.
ead-l'd eflect'n.	Square bar.	Flat bar.	
.23	.166	.200	.60
.20	.193	.234	.65
.14	.208	.240	1.25
.12	.245	.244	all.
.14	.241	.236	all.
.14	.245	.244	all.
.18	.242	.241	all.

n along with the increase of nd to find out which produced ll, etc., we made in the same introducing into the melted on and carbon, the same as in

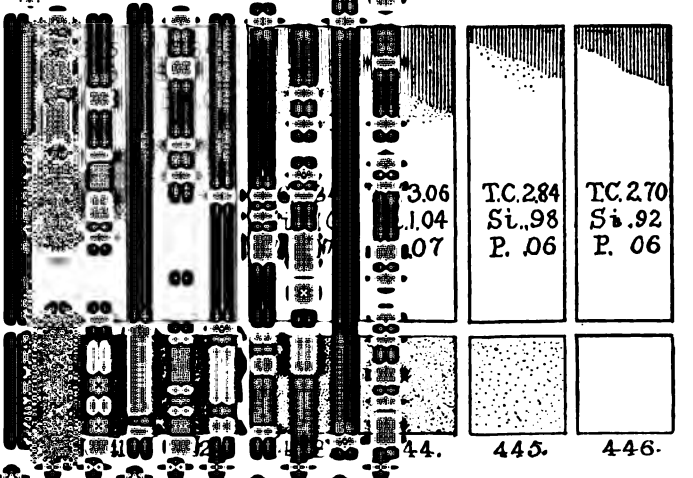


ne results are as fol-

	SHRINKAGE.		Chill.
	Square bar.	Flat bar.	
8	.186	.186	.40
5	.216	.216	.70
3	.255	.255	2.00
9	.258	.258	all.
3	.264	.264	all.
4	.263	.263	all.

m the corresponding
hows approximately
smaller with sulphur
er with sulphur are

in a crucible using
ed 0.186 silicon and
n and carbon as sul-



...and chill are shown in Fig. 5.

II.

Dead-load deflection.	Shrinkage.		Chill.
	Square bar.	Flat bar.	
—	.002 —	.014 +	.20 +
—	.018 +	.018 +	.05 —
—	.005 +	.015 —	.75 —
—	.006 +	.014 —	—
—	.017 —	.028 —	—
—	.013 —	.019 —	—

II.

Dead-load deflection.	Shrinkage.		Chill.
	Square bar.	Flat bar.	
.10	.246	.236	all.
.15	.248	—	all.
.11	.249	.229	all.
.09	.238	.223	all.
.07	.232	.233	all.

Shrinkage.		Chill.
Square bar.	Flat bar	
.250	.....	all.
.250	.237	all.
.246	.236	all.
.239	.....	all.

The subtraction of Series XIV. from XIII. gave:

Series XV.

Mixture.	Strength.		Dead-load deflection.	Shrinkage.	
	Dead load.	Impact.		Square bar.	Flat bar.
White iron, with 0.00 S.	77 —	111 —	.03 —	.004 —	.....
" " .10 S.	87 +	42 +	.05 +	.002 —	.....
" " .80 S.	71 +	48 +	.01 +	.003 +	.007 —
" " .80 S.	22 —	18 —	...	.001 —	.....

We made another series in a crucible using $F^{L}M$ and the iron sulphide with 2.5 per cent. S, and in this case we added enough silicon to keep this element at 1.25 per cent. in all cases. The results were as follows:

Series XVI.

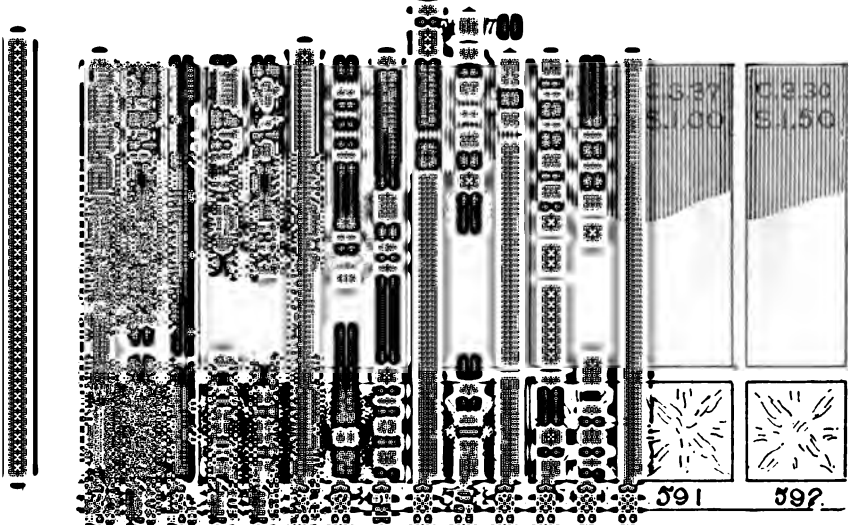
Test No.	Mixture.	Strength.		Dead-load deflection.	Shrinkage.		Chill.	Per cent. carbon.
		Dead load	Impact		Square bar.	Flatbar		
429	$F^{L}M$ with 0.00 S.	335	330	.23	.166	.200	.60	3.50
587	" " .10 S.	375	310	.23	.189	.201	.60	3.49
588	" " .30 S.	343	279	.12	.197	.239	.80	3.46
589	" " .50 S.	355	305	.10	.221	.240	1.00	3.43
590	" " .80 S.	390	279	.12	.241	.244	all.	3.39
591	" " 1.00 S.	493	347	.15	.250	.248	all.	3.37
592	" " 1.50 S.	383	288	.12	.249	.240	all.	3.30
593	" " 2.00 S.	410	322	.14	.251	.244	all.	3.22

We made no cast of $F^{L}M$ alone, and we, therefore, record that mentioned in Series X.

The grain of fracture is shown in Fig. 7.

The grain of 593 is exactly the same as 592.

In Series XVI., as the silicon did not vary, it leaves only one element of uncertainty, viz., the carbon-content, which was reduced to 3.22 in the last combination. To ascertain the effect of such a reduction of carbon with no reduction of silicon and without sulphur,



adding wire to re-

	SHRINKAGE.		Chill.
	bar.	Flat bar.	
6		.200	.60
4		.226	.60
97		.....	2.00
6		.261	all.

Series XVI. with
ent. of sulphur re-
ite, and increased
not turn the iron

ed the sulphur in
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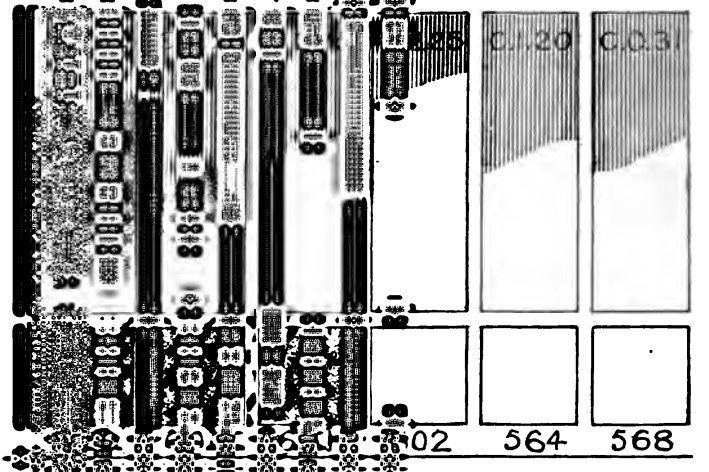

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stitute, 1888, No. 1, p. 28.

Mr. Smith, in the same laboratory, mixed with gray cast-iron enough of the sulphide to add 2.68 per cent. sulphur, but found only 0.78 per cent., nearly three-quarters being lost. The product was white, as there was not enough silicon present to overcome this amount of sulphur. This was remelted with a further loss of over half the remaining sulphur, leaving a *mottled* iron; that is, the iron contained enough silicon to overcome the influence of 0.40 per cent. of sulphur.

He mixed another lot of gray cast-iron with enough of the same sulphide to make 0.90 per cent. sulphur, with a loss of nine-tenths of the sulphur in melting.

At another time he took a No. 2 gray-iron and mixed the sulphide in sufficient quantity to make the sulphur 1.65 per cent., and lost about one-third. The product was white.

In all of the above experiments of Weston and Smith, except the first, graphite separated from the iron and appeared on the outside of the metal.

This would not indicate that the sulphur necessarily caused the carbon to retain its combined form.

In the fourth experiment of Mr. Weston, he began with a perfectly white iron and remelted it twice, the first time with 1.24 per cent. sulphur, and finally with 0.72 per cent. More than half that was added remained, and yet the casting was mottled. We have proved elsewhere that if a gray iron has its silicon lessened sufficiently, it will be mottled and white. If it contains but a small percentage of silicon, it cannot be anything but white. In every case Messrs. Weston and Smith used clay crucibles, and the iron would take some silicon from this source, while the grayness of the mottled product shows that the sulphur did not counteract the influence of silicon. In Mr. Smith's experiments gray cast-iron is taken in every case, but the sulphide which he adds is made up of 70 per cent. of pure iron and 30 per cent. sulphur, and therefore the sulphide addition materially reduces the silicon and carbon in the iron, and in this case it was enough to render the iron white; but by remelting enough silicon was taken from the crucible to restore the iron to a mottle.

In the experiment of Mr. Smith, where he used a No. 2 iron, the whiteness was no doubt largely due to the dilution by the addition of the sulphide; for the iron was No. 2—that is, close-grained from containing a small amount of silicon.

We have commented thus fully on the experiments of these gentlemen because they have been quoted to show that sulphur compels

carbon to take the combined form, and that sulphur will drive out carbon—the fact being wholly overlooked that the addition of sulphide diluted the carbon and silicon, and thus whitened the iron. The fact of carbon being on the surface of the casting would seem to prove that sulphur will expel carbon.

Our own experiments which we have described are in every way similar to those of Messrs. Weston and Smith, except that we kept the percentages below 1 per cent., and melted a large quantity of material. Our F[L]M iron contained 3.50 per cent. of carbon and 1.25 per cent. of silicon, or just enough to make the iron gray. The addition of sulphide diminished the carbon in every case and diminished silicon in some cases. Both reductions tend to make the iron white.

All these tests show that sulphur, if present to any extent in cast-iron, tends to increase shrinkage and to turn the iron white; but, on the other hand, to prove this tendency, we have been obliged to resort to unusual methods, and we have added percentages of sulphur which can never be found in commercial pig-iron.

At a number of furnaces ores are used that contain over 3 per cent. of sulphur. The fuel also contains nearly 1 per cent. of sulphur.

This condition of things would cause the largest possible percentage of sulphur to be taken up by the iron, but all agree that in white iron not more than 0.75 per cent. of sulphur, in mottled iron not more than 0.25 per cent., and in gray foundry iron not more than a few hundredths of one per cent. can be found.

The rapid melting of pig-iron in a cupola, in which the coke is largely desulphurized before it reaches the point where the iron is melted, cannot possibly much increase the sulphur-content of the pig-iron, and much testimony goes to show that a considerable part of the sulphur already in the pig is driven off during remelting. Mr. Kirk states that he used in a foundry mixture pig-iron containing 0.626 per cent. of sulphur, and that most of the sulphur was lost in remelting. Prof. Turner mixed his iron, containing 11 per cent. sulphur and 10 per cent. silicon, with pig-iron in proportions to give him 5 per cent. of sulphur; but it only contained 0.4 per cent., nine-tenths of the sulphur having disappeared by a single melting.

The pig-iron will never contain more than 0.10 per cent., and probably will never have one-half that amount of sulphur. Examining the foregoing experiments with a view to ascertaining the

influence of 0.05 per cent. of sulphur, we must at once conclude that this amount will not exert any appreciable deleterious influence, and that what little is done in this direction is at once corrected if we slightly increase the silicon.

Remembering that the only noticeable effect of these small percentages of sulphur would be to slightly raise the shrinkage, the above conclusion seems to be also proven by the fact that in a cupola running on a substantially uniform mixture, and returning from 25 to 40 per cent. of its iron to the cupola to be remelted over and over again each day, the castings will almost invariably have a less shrinkage than the average of the pig-iron used, and yet we think, as a general thing, the castings will contain more sulphur than the average of the pig-iron, and the silicon will always be less than the average of the silicon in the pig-iron.

The depth of chill does not seem to be influenced by these small percentages of sulphur, and there is no testimony to show that there is any relation whatever between the sulphur-content and the strength in pig-iron or in ordinary castings.

In fact, it is generally accepted that one brand of Swedish pig-iron owes its strength and adaptability for gun construction to sulphur-ore added in the furnace.

If we have succeeded in dispelling the superstition regarding the influence of sulphur in the fuel upon the castings produced, we shall hope to be able, at a future time, to propose an explanation of the production of inferior castings from time to time from a uniform mixture of pig-iron.

ELECTRICITY IN MINING.

BY F. O. BLACKWELL, LYNN, MASS.

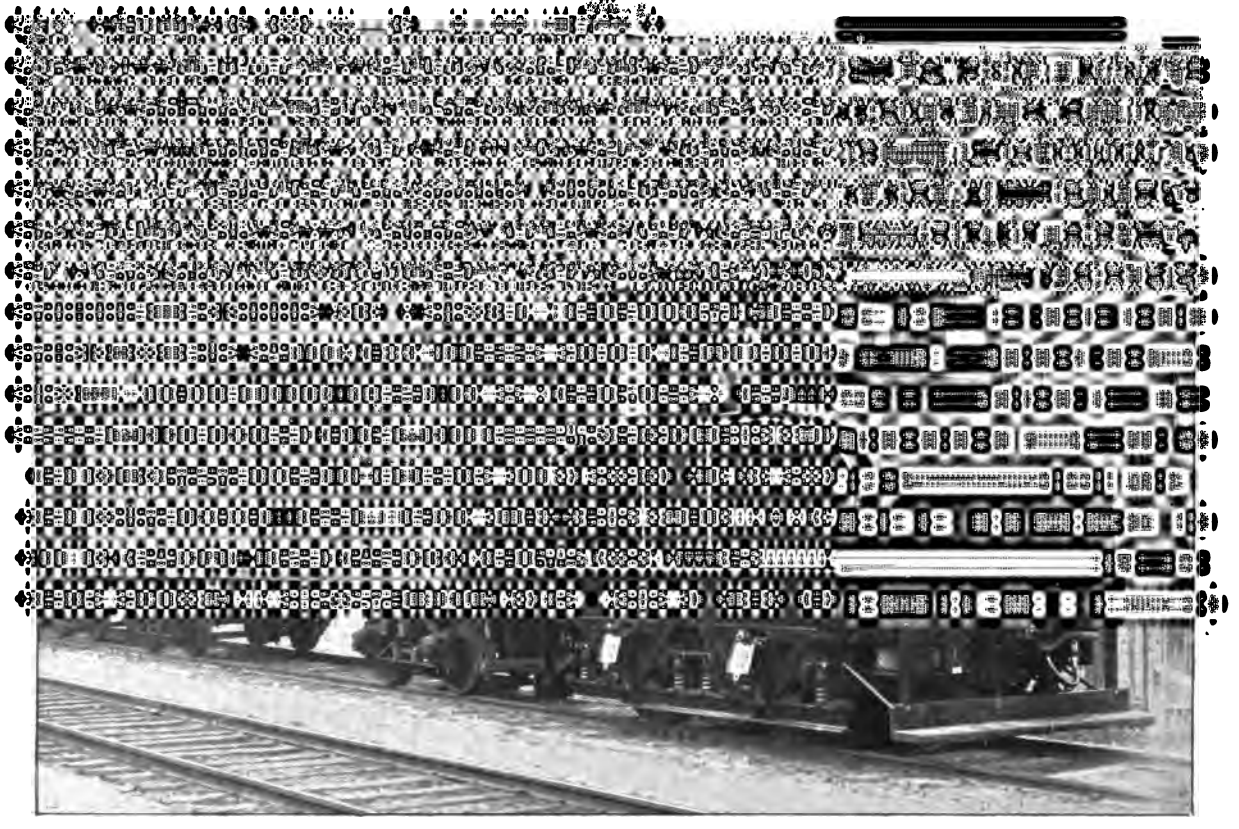
(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

IT is roughly estimated that some three hundred companies in the United States engaged in mining and the kindred arts now employ electricity in their operations. As all these plants have been installed within the last few years, it is evident that mining engineers have been quick to appreciate the great advantages of the use of electricity and adopt it for their many requirements. In

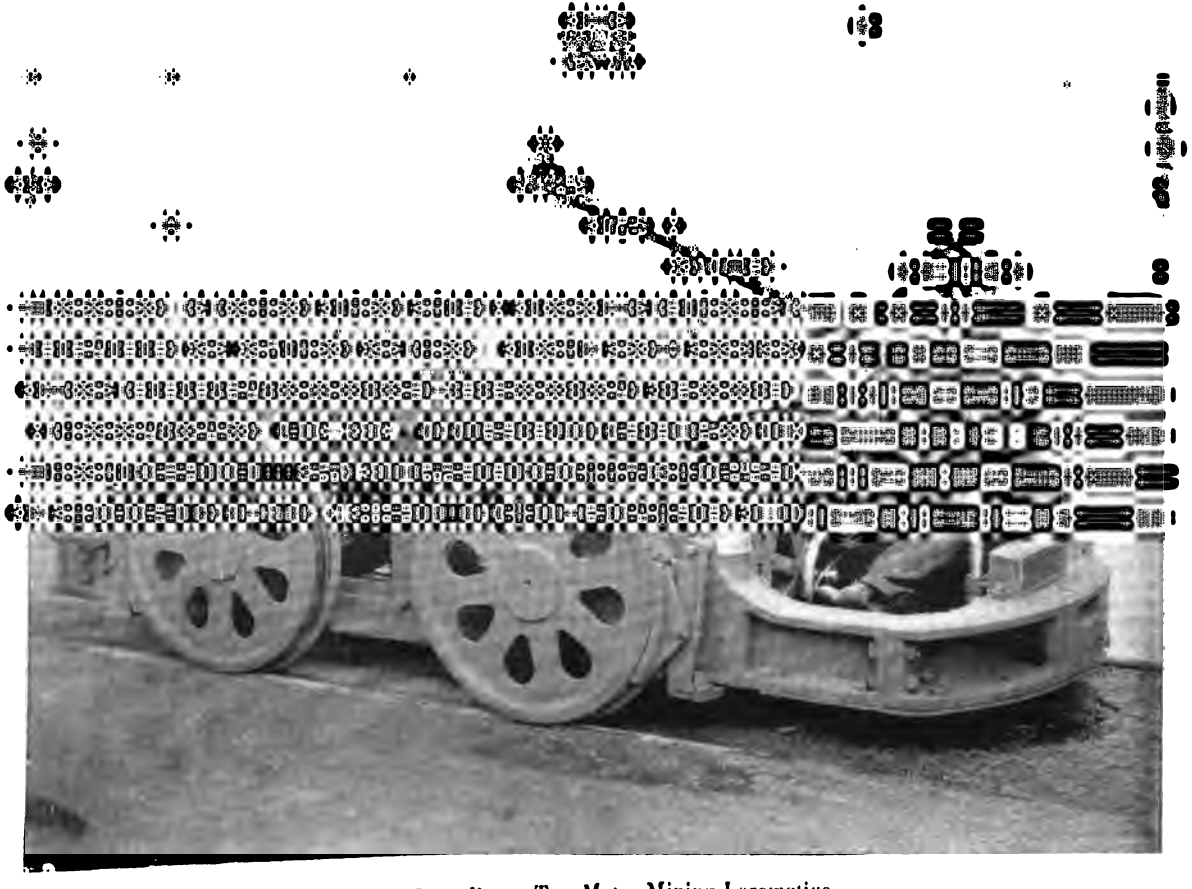
underground workings the chance of accident resulting in loss of life and destruction of property is, at the best, great. Humanity and economy both demand that any means that will secure greater safety should be eagerly grasped. It is an established fact that to add to the comfort and facilitate the work of the miner is to diminish financial risk and increase profits.

Electricity tried under the arduous conditions of mining service has been shown to be peculiarly efficient, safe, and reliable. It presents a system of the greatest simplicity, completeness, and flexibility, permitting power from one source to be distributed in units of any desired size and for any purpose to the places where it can be employed to the greatest advantage, thereby securing the minimum consumption of power and expenditure of labor. With electricity there is neither friction, heat, nor condensation. There is no leakage nor loss of power when not in use, which especially recommends it for intermittent work. It is not affected by heat or cold, and does not vitiate the air, as is the case with steam and compressed air. The rapid deterioration of timbering, a source of great expense in all mines, due to bad air and heat, is to a great extent obviated. It has been urged against electricity that it increases the risk of fire. As a matter of fact it greatly decreases it, as the statistics of insurance companies testify. With proper safety-devices and a system of concentric wiring it is practically impossible to start a fire from the current. To the engineer accustomed to speed-indicators, pressure-gauges, and indicator-cards, electrical methods of measurements seem particularly simple. The work being done by motor or generator at any instant can be read directly from a scale and, if desired, automatically recorded. If necessary, motors can be controlled from a distance without difficulty.

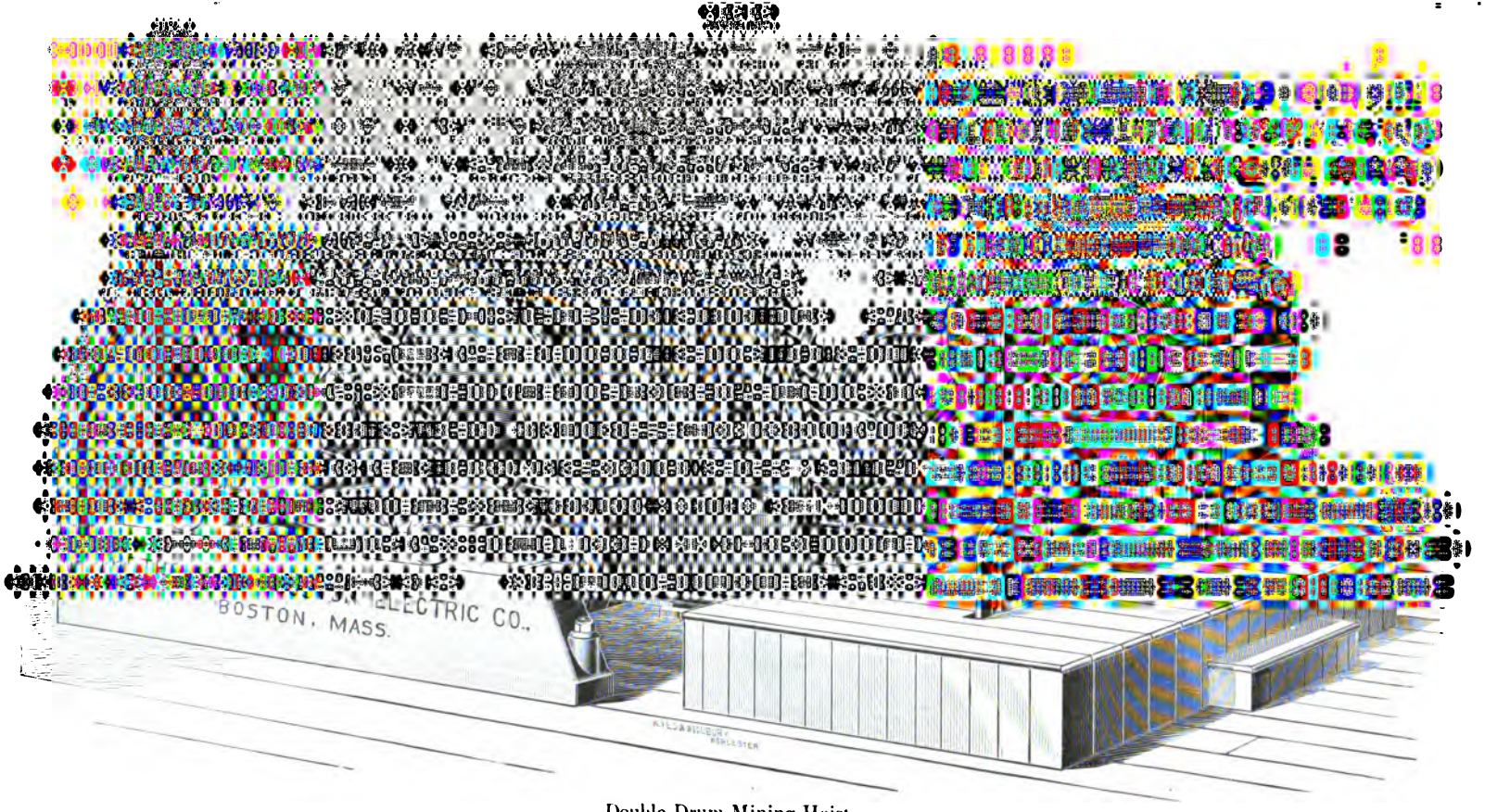
The prime source of power is first to be considered. By coversion into electrical energy, water-power, even at a considerable distance from the mine or mill, can be made valuable for all purposes, and steam power can be so located as to secure fuel and water cheaply. In addition to this, one large engine costs less, is more evenly loaded, requires less attendance, and is necessarily more efficient than a number of small ones. The introduction of electricity has in this way made important reductions in the cost of power, and there are cases in which it would be impossible to run without its help. An example is furnished by the Virginius Mine at Ouray, Colo., to which 300 horse-power is carried at 800 volts from a water-power four miles distant. The cost of coal at the mine was



Thirty-Ton Passenger Locomotive.

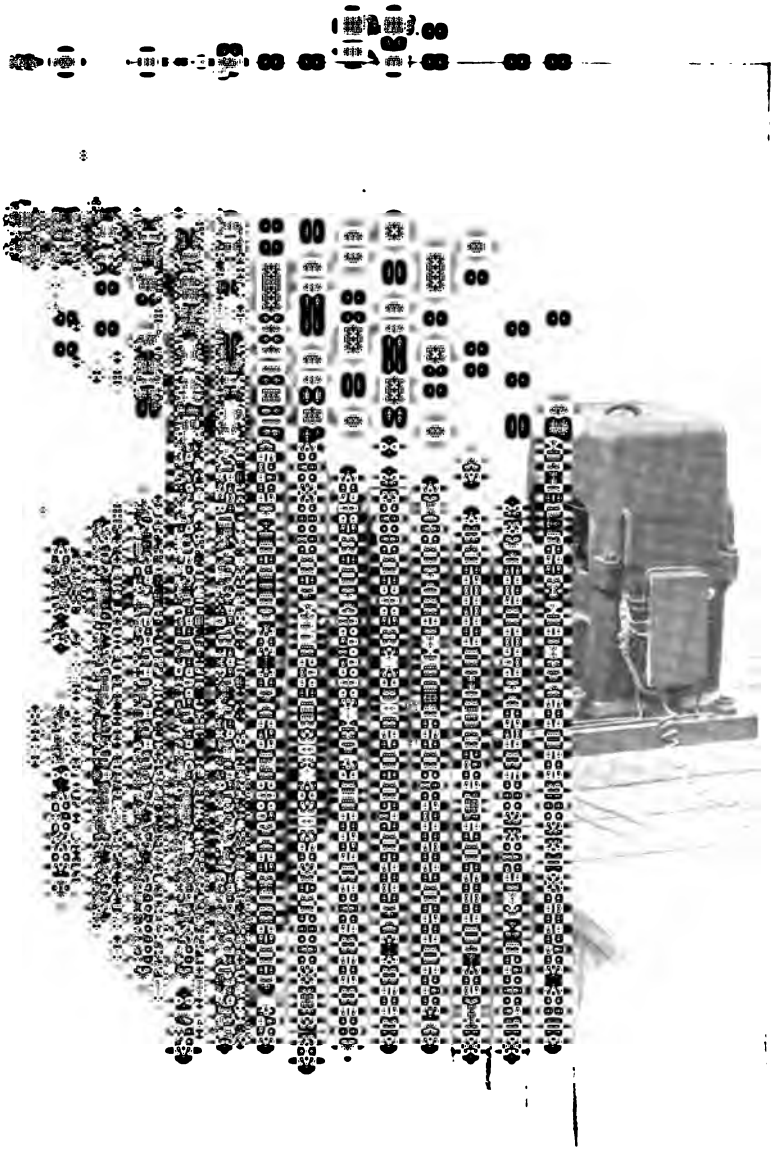


Fifty Horse Power Two-Motor Mining Locomotive.



Double Drum Mining-Hoist.

Pump.



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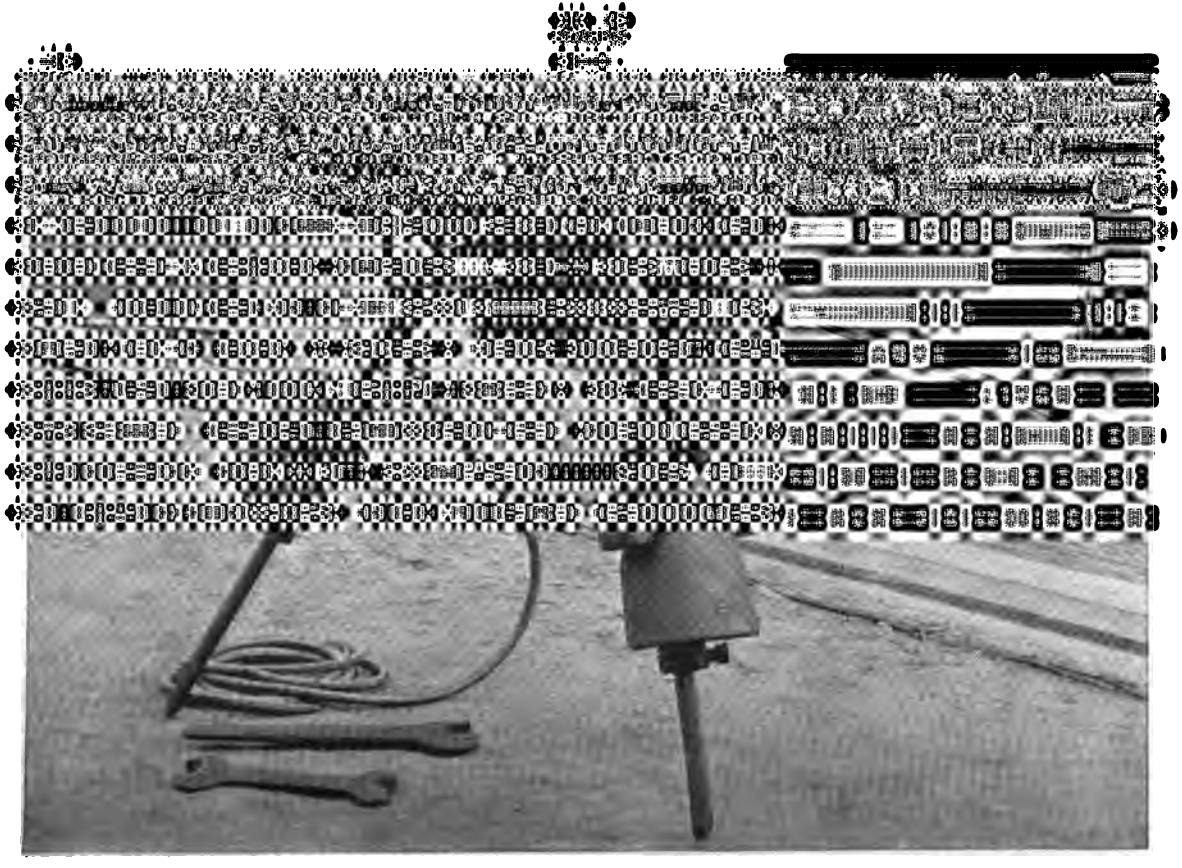
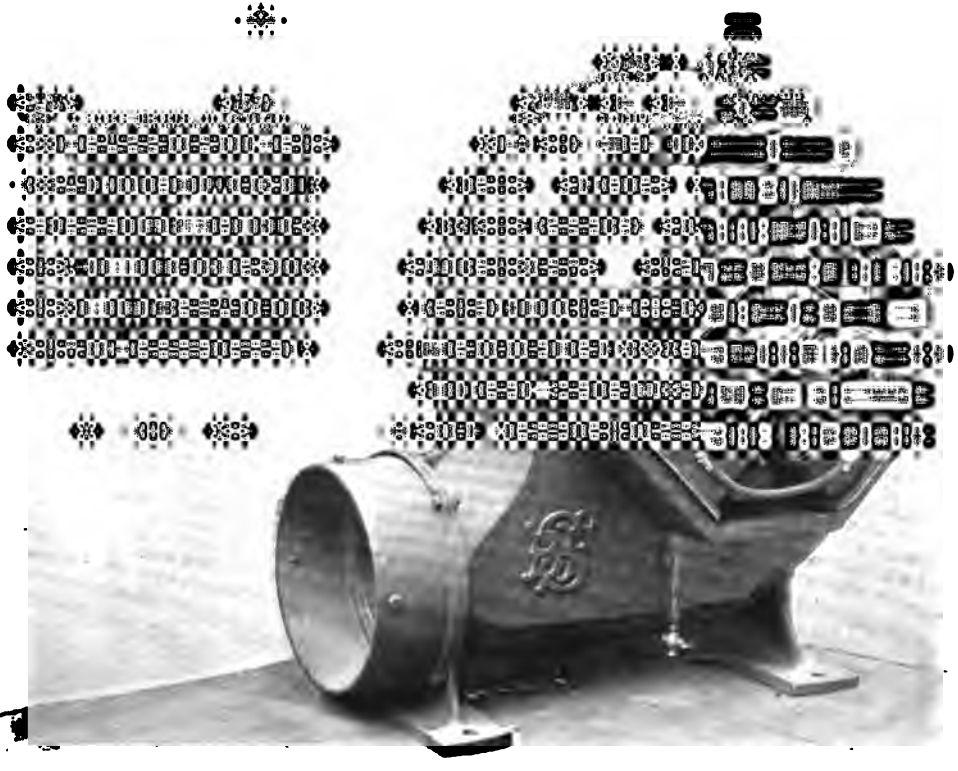


Electric Percussion Drill.



Electric Ventilating Set.

formerly $18 per ton, which would amount, for the present plant, to about $80,000 per year, equalling the total cost of the electric plant. The item of fuel was a complete saving, the expense of operating the steam and electric plant being about the same in other respects. Several mines in Colorado are operated by electricity that could not be by steam, on account of their situation on the face of precipitous cliffs, up which the transportation of water and fuel would be nearly impossible. The character of the country over which the power had to be carried for the Virginius plant is exceedingly rough. A portion is at an elevation of 12,000 feet above sea-level and well above the snow-line.

Electric Generators.—Generators can now be obtained of any size and designed to run at any reasonable speed for belting or direct connection to engine or water-wheels. The largest generator in the world is now running in the power station of the Intramural Electric Railway at the World's Fair in Chicago. It is of 2000 horse-power, and directly connected to a compound condensing-engine running at seventy-five revolutions. The electric generator is substantially the same as the motor, and both can be relied upon to give an efficiency of from 90 to 95 per cent.

Electric Power Transmission and Distribution.—The cost of copper, with any fixed loss, power, and distance varies inversely as the square of the voltage. It is, therefore, evident that as high a voltage as possible should be used if economy of copper alone is to be considered. When the power is carried over long distances the cost of copper is the largest item of expense. For general distribution, especially underground, convenience of insulation and handling are of more importance, and call for a low potential. Nearly all the plants now in operation are supplied with current at 220 or 500 volts. There are a number, however, in which voltages of 1000 and over are in use—notably at the Poorman, Comstock, and Calumet and Hecla mines. When bare wires are used, as for haulage, we are limited to a potential of 500 volts. Direct-current generators are confined, by difficulties of construction, to potentials of less than 1500 volts. The distance over which direct current can be economically carried at this potential is about four miles. Above this point alternating currents are used.

The long-distance transmission of power was first brought prominently before the public by the experimental line constructed between Lauffen and Frankfort two years ago. The power of the Lauffen Falls, converted into electricity, was transmitted 115 miles

to the Exposition at Frankfort, where it operated a number of motors. The distance was beyond the limits of commercial success, but it demonstrated the possibility of the system. To-day, plants are in operation, transmitting current for light and power, at Walla Walla, Wash.; Portland, Ore.; Redlands, Cal.; Telluride, Col., and Hartford, Conn. The distances vary from four to thirteen miles.

Alternating currents are particularly desirable, on account of the ease with which the electrical pressure can be changed. By means of transformers without moving parts, the high potential used for transmission is converted into low pressure for distribution. Alternating generators are wound for as high as 5000 volts; but it will probably be found better to limit them to 2500 volts. This potential permits of economical transmission to a distance of seven or eight miles. Above that distance, step-up and step-down transformers are used. At present, we do not care to go above 10,000 volts, which places the limit of about twenty-five miles to practical work. Alternating-current motors possess nearly the same properties as those built for direct current. They have the advantage of being commutatorless, but cannot be so heavily overloaded as a series-wound direct-current motor. They are, therefore, not as suitable for railway or hoisting service. Direct currents can, however, be readily obtained from alternating by means of a rotary transformer, which is a combined alternating motor and direct-current generator. Motors have been designed to meet all the special requirements of mining work, and I will give a short description of some of the more recent applications.

Electric Haulage.—In no application of electricity, except lighting, has such success been met with as in the operation of railways. Above ground, it has already supplanted animal power, and in many cases steam. For underground haulage, the ready control, compactness, and freedom from smoke, render it still more desirable; and already electric locomotives are in some thirty mines. I would call particular attention to the saving that can be effected in the size of entries. The electric locomotive is so designed as to occupy no more space than the car which it is to haul. With any other method of traction considerably more height or width is necessary. In coal-mines, in which there are narrow seams, this is especially noticeable, as much rock has to be blasted away to admit of the passage of mules. By using electric locomotives the blowing down of the roof is entirely done away with. The increased speed also permits a larger tonnage

to be taken from the same outlet and with fewer turn-outs, switches, and cars. Locomotives are now to be obtained of any size, and to operate on any track-gauge not less than eighteen inches. The Baltimore and Ohio Railroad Company, after carefully considering all systems, decided to equip their tunnel through Baltimore with electricity, and push through all their trains by electric locomotives. The first of these locomotives is now nearly completed at the Schenectady works of the General Electric Company. Its weight is 90 tons, and at 15 miles per hour it will develop 1500 horse-power. Fig. 1 shows a locomotive of 30 tons weight which is used for surface railways. A motor drives each axle, no gearing being required. For mining haulage large sizes are not required; those now in use varying from 150 to 10 horse-power, the most common size being 30 horse-power. In the cuts accompanying this paper two types of locomotives are shown. At Rock Springs, Wyoming, there is in operation a locomotive of 80 horse-power. It is operated by a single motor, geared to both axles, the connection to the axles, however, being made through a flexible coupling, allowing the entire weight to be supported on springs. Fig. 2 shows a locomotive of 50 horse-power driven by two motors, one on each axle. It will be noted that no part of the machine is wider or higher than the wheels. The larger sizes of locomotives, generally, are constructed with one motor, and the smaller with two. All locomotives in use are controlled by rheostats, and the speed under load varies from six to twelve miles per hour.

Electric Hoisting.—Electric hoists are now largely in use, and follow, as nearly as possible, the methods and construction approved for steam-hoists. The governing mechanism is similar, rheostats replacing the steam-controlling gear, and the brakes and clutches are the same. The rotary motion of the motor avoids the use of connecting-rods entirely. If it is desired to lower by power, the current can be admitted to the reversed motor. For small hoists used in winzes, and in timber-construction work, electricity is well adapted, the power-connection being easily and quickly changed. The simplicity of the application of electricity, and the consequent economy, is well exemplified in the equipment of the Brooklyn docks of the Wilson Steamship Line, where nine electric hoists, constructed by the General Electric Company, have been in continuous operation for two years, with a total cost for repairs of $23. The double-drum hoist, shown in Fig. 3, is designed for a double-compartment shaft. It is furnished with post-brakes and jaw-clutches of the ordinary

pattern. Special hoists, for use underground, are equipped with iron-clad motors, so as to be thoroughly protected. An efficiency of from 50 to 60 per cent. is usually obtained between the power taken by the motor and the foot-pounds hoisted.

Electric Pumping.—A number of large pumping-plants are now in operation equipped with electric motors. It is necessary, in order to turn the reciprocating motion of a plunger-pump into a rotary motion, to equip it with crank-shaft and connecting-rods. This at the same time insures a steady flow of water. Some difficulty is experienced in cutting down the speed of electric pumps, as is done with steam. The general practice has been to stop and start, in order to decrease the capacity. The best method, and one going largely into use, is to make the fields of such strength as to give the minimum speed desired, so that, by decreasing the current in them, the speed may be increased up to the maximum output. Where many pumps of nearly the same size are in operation, a convenient method of regulation is to throw the pumps into multiple-series combinations with each other. They may also be controlled by varying the electro-motive force supplied them from the generators. Rheostats answer well enough for small pumps. Triplex single-acting and duplex and triplex double-acting all work well and give an efficiency of over 70 per cent. between the electric power taken by the motor and the water delivered by the pumps. If the lift is small and the water contains much solid matter, centrifugal pumps may be used, but their efficiency is low. At the World's Fair exhibit of the General Electric Company is shown a Blake pump directly connected to a slow-speed multipolar motor of 100 horse-power, requiring only one gear-reduction. The capacity of the pump is 500 gallons at 500 feet head. Fig. 4 illustrates a sinking-pump of 120 gallons capacity, to work against 200 feet head. It will be noted that the motor and gearing are completely inclosed in a cast-steel case, and cannot be damaged by being flooded. Fig. 5 shows a Lawrence centrifugal pump with direct-connected motor.

Electric Air-Compressors.—Statements made above regarding hydraulic pumps, apply equally well to air-compressors, except that, as air has not the inertia of water, it can be automatically loaded and unloaded without throwing any strains on the mechanism, the motor running constantly at a fixed speed. A decided saving of power can be effected by locating drill-compressors near to the drills, and thus avoiding losses by leakage and shrinkage in the pipes.

Electric Drilling.—Although it has been a matter of great diffi-

culty to make an electric percussion-drill which would stand the continual abuse and hard usage to which air-drills are subjected, they are at present in constant and successful operation. By care in designing the coils, so as to make them fire-proof and rigid, they have been made to stand the strain. The drill consists of an outer iron-pipe casing, inside of and attached to which are two coils and ratchet-mechanism. The plunger, equipped with the ordinary chuck and rifle-nut, is in the center of the coils. The coils are supplied with current alternately, and draw the plunger up and down at a speed fixed by the generator which supplies the current. An electric drill mounted on a tripod is shown in Fig. 6.

Electric diamond-drills are in use for drilling solid holes and for removing cores for prospecting purposes. For prospecting, both above and under ground, the electric drill is particularly available, as it is extremely light and compact, and temporary wires can be run to places where it would be difficult to carry steam-pipes or boilers. Fig. 7 shows a diamond prospecting-drill with hoist and pump. It is driven by a 2¼ horse-power motor, will remove a 1⅜-inch core, and can drill 600 feet deep without difficulty.

Electric Coal-Cutting.—Electric coal-cutters are now largely in use in the bituminous mines. In the machine most employed the coal is undercut by means of bits set in a rotary bar on the end of a sliding frame which is fed into the face of the seam. Other cutters are constructed with a sprocket-chain, to the links of which are affixed cutting-tools. Machines of this kind can be fed either in or along the face of the coal, for long-wall or room-working. In both of these the electric motor is built into and forms part of the frame, adding but little to its weight. In exceedingly hard or pyritiferous coals, which cannot be cut with a continuously-moving cutter, an electric pick-machine is advantageously used. This also has the advantage of giving a kerving wider at the front than at the back of the cut, which allows the coal to fall outward, and more lump-coal to be gained. A pick-machine of this kind can be seen at the World's Fair exhibit of the General Electric Company. The motor draws a projectile back against a spring, and releasing it, lets the pick fly against the face of the coal at the rate of 150 blows a minute. Electric drills for putting in holes for blowing down coal after it has been undercut or from the solid, as is done in anthracite, are also used. Mounted on a column, a machine of this kind is free to drill in any direction, from horizontal to vertical. A drill of this type, of 100 pounds' weight, will easily drill a 1½-in. hole at the rate of 6 feet per minute in hard or soft coal.

Ventilation.—In order to obtain the best results from fans and blowers, it is often desirable to locate them at the most distant points from the surface. This is done more easily in the use of electricity than of any other power, and the blowers can be readily advanced as the workings are pushed deeper. The electric motor is especially suitable for high-speed blowers, which are efficient and occupy but small space. Much saving in piping can also be effected by using higher velocities and forcing air out from the inside rather than sucking it from the surface. Fans can be controlled by a shutter on the outlet-pipe, or the speed of the motor may be varied. Fig. 8 shows a No. 4 Sturtevant blower, directly connected to a two-horse-power motor.

Electric Lighting.—It has been found that much more work can be got from men by giving them better illumination. By avoiding the use of oil-lamps and candles, the air is left purer, and both time and power are saved by doing work underground which would otherwise have to be done on the surface. Electric lighting also reduces the risk of accident by calling attention to conditions which would otherwise pass unnoticed. In gaseous mines, where many explosions have resulted from the reckless use of miners' lamps, electric lighting is invaluable.

Metallurgy.—It is impossible to go fully into the electro-metallurgical and electro-chemical processes now in use. The refining of black- and blister-copper has reached large proportions, fully one-third of the copper refined in this country being electrically treated, and considerable quantities being shipped abroad. By this process gold and silver are obtained from the matte, the recovery of which would be impracticable by any other method. Gold, silver, and lead are also beginning to be refined electrolytically. Aluminum and silicon are produced almost exclusively by electric smelting and reducing. Caustic soda, sodium, chloride of lime, and vermilion are commercially obtained by electrolysis.

I have not, within the scope of this paper, been able to deal with all the many and constantly increasing applications of electricity, but enough has been said to make evident its far-reaching importance to the mining industry.

RECENT ADVANCES IN PYROMETRY.

BY W. C. ROBERTS-AUSTEN, C.B., F.R.S., PROFESSOR OF METALLURGY ROYAL COLLEGE OF SCIENCE, CHEMIST OF THE MINT, LONDON.

(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

THE subject with which the Council of the American Institute of Mining Engineers has entrusted me is one of much interest. It has been so admirably treated in America by Prof. Carl Barus* that I should have hesitated to deal with it had not the adoption of pyrometric methods in England recently occupied much attention, especially in relation to metallurgical industries and research. I shall endeavor to show what is the present state of our knowledge of practical pyrometry by briefly tracing the history of the efforts which have been made to measure high temperatures. This paper will, therefore, be limited to the consideration of those forms of appliance which have either marked distinct stages of advance, or have remained in use with more or less modification through a considerable range of time.

The earliest pyrometers were essentially thermoscopes, and although their graduation presented great difficulties, their importance as affording a means for the measurement of high temperatures has been recognized for centuries. It would be difficult to illustrate this better than by a brief record of the testimony which has from time to time been offered by those who have had to apply the heat of furnaces in research or in industry, and it is mainly for the sake of the light incidentally thrown on the progress of both that the following historical notes are offered.

In the eighth century, Geber, the chemist, wrote a treatise on furnaces, and showed that he was familiar with many and varied means of applying heat; but he points to the difficulties that are met with in conducting operations at high temperatures, which he attributed to inability to measure heat, his actual words being: "*sed quoniam non est res ignis, quæ mensuari possit.*" †

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* *United States Geological Survey*, Bulletin 54, 1889.

† From the edition of his work, *Summa Perfectionis Magisterii*, published in Venice, 1542, p. 28.

The date of the invention of the ordinary thermometer is not well fixed, the conception of the instrument being variously attributed to Drebbel, Santorio, and Flud; but I gather from a delightful article lent me by my friend, Prof. S. P. Thompson,* whose authority in connection with the early history of science is beyond question, that the claims of Santorio† are supported by Borelli‡ and Malpighi,§ while the title of Drebbel is considered as undoubted by Boerhaave|| and Musschenbroek.¶ Flud repeatedly figures the common air-thermometer in his singular work,** *De Philosophia Moysiaca.*

The earliest air-thermometer I have found with a movable index is described by Robert Boyle, and consists of the ordinary glass bulb, with a slender stem, in which a globule of mercury moves with the expansion or contraction of the air in the bulb.††

In Waller's translation of the *Proceedings* of the Accademia del Cimento, figures of many ancient thermometers will be found. The one here reproduced, Fig. 1, is perhaps the most remarkable. Some of my readers may have shared with me the good fortune to have seen the actual instrument which was exhibited in 1877 at the Loan Collection of Apparatus in London. It consists of a lower bulb, from which a long spiral tube proceeds and terminates in a smaller bulb at the upper end of the instrument. The spiral tube is dotted at

* *Library of Useful Knowledge*, article "Thermometer and Pyrometer."

† *Comment. in Galen. et in Avicen.*

‡ *De motu Animalium*, Prop. CLXXV.

§ *Opuscula Posth*, p. 30.

|| *Elementa Chemiæ*, tom. i., p. 152.

¶ *Elem. Phil. Nat.*, par. 780, *Tentam. Exp. Acad. Cim.*

** *De Philosophia Moysiaca*, folio, Goydœ, 1638.

†† We are greatly influenced by heat and cold, and it is perhaps natural that the names of Celsius, of Fahrenheit, and of Reaumur, which are intimately connected with instruments for measuring variations of temperature, should be prominently remembered even by unscientific persons who have but little idea of the real nature of the work of these men. In illustration of the fact that their names are household words as experimenters, it may be worth while to quote the reply given by a candidate to the question: "Describe any way in which the velocity of light has been measured." The answer, which Dr. Oliver Lodge (*Literary Blunders*, by H. B. Wheatley, F.S.A., 1893, p. 185) tells us was given, is as follows: "A distinguished but heathen philosopher, Homer, was the first to discover this. He was standing one day at one side of the earth looking at Jupiter, when he conjectured that he would take sixteen minutes to get to the other side. This conjecture he then verified by careful experiment. Now, the whole way across the earth is 3,072,000 miles, and dividing this by 16 we get the velocity 192,000 miles a second. . . . . P. S.—I think the gentleman's name was Romer (Reaumur), not Homer; but anyway, he was 20 per cent. wrong, and Mr. Fahrenheit and Mr. Celsius afterwards made more careful determinations."

intervals with beads of glass to mark degrees. It is described in the account of the experiments made before the Accademia del Cimento as being "of so exquisite a sense that the least flame of a candle affects it."

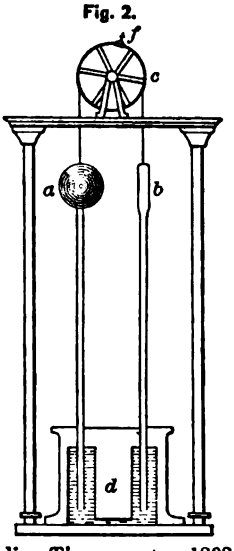
I have elsewhere called attention* to the fact that Boyle alludes to Cornelius Drebbel as having invented "an automatous musical instrument and a furnace which he could regulate to any degree of heat by means of the same instrument."†

Space will, however, only permit me to refer to one instrument of singular interest from its relation to later appliances described in

Fig. 1.

Ancient Thermometer.

Fig. 2.



Recording-Thermometer, 1808.

this paper. It is a recording-thermometer, which appears to have been devised by Dr. Cumming,‡ of Chester, about the year 1808. It is shown in Fig. 2, in which *a* represents an air-thermometer; *b*, a barometer to compensate the influence of variations in atmospheric pressure on the instrument, suspended from the opposite side of a wheel *c*; *d* is a syphon-cistern, in both sides of which the mercury will always remain on the same level; and *f* is an index, to which a *pencil* may be fixed for tracing the variations of the instrument on a plate revolved by means of clock-work. I believe this to be the

* *Proc. Roy. Institution*, 1892.

† *Boyle's Works*, Shaw's edition, vol. iii., p. 38, 1738.

‡ *Library of Useful Knowledge*, p. 46.

earliest instrument by the aid of which a time-temperature curve could have been traced. Mr. Kewley devised an instrument, patented in 1816, in which a differential mercurial thermometer was fixed to the beam of an ordinary balance.

Hitherto, thermometers capable of measuring very moderate degrees of heat have only been dealt with, and it is now necessary to turn to the consideration of pyrometers, or instruments capable of indicating temperatures beyond the range of the ordinary mercurial thermometer. I have not found a reference to earlier work than the work of Sir Isaac Newton,* who, in 1701, applied his law of cooling to high temperatures, and, in notes which accompany his *Scala Graduum Caloris*, showed that he knew that the freezing point of lead differs slightly from its melting point. Amonton made similar experiments in Paris at about the same time.

Musschenbroek's pyrometer was constructed in 1731.† He employed the expansion of a metallic rod for indicating the temperature to which the rod was raised. An early copy of his instrument was exhibited in the Loan Collection of Scientific Apparatus, 1877, and was undoubtedly one of the oldest of its kind. Very many instruments of similar construction followed, but these must be passed over, as the principle on which they depend has gradually been abandoned in accurate modern pyrometry. Reference must, however, be made to Josiah Wedgwood.‡ The measurement of the contraction of clay at high temperatures was the basis on which his instrument rested, and, in communicating a description of it to the Royal Society, we find him, one thousand years after Geber had said that "fire cannot be measured," still lamenting the want of suitable instruments, saying: "How much is it to be wished that the authors (to whom he refers) had been able to convey to us a measure of the heat made use of in their valuable processes; . . . . a red, bright red, and white heat, are," Wedgwood adds, "indeterminate expressions; and even though the three stages were sufficiently distinct from each other, they are of too great latitude;" and pass into each other "by numerous gradations which can neither be expressed in words nor discriminated by the eye."

Guyton Morveau, 1808, fully recognized the value of this appli-

* *Phil. Trans. Roy. Soc.*, vol. xxii., p. 824.

† It was constructed after the description and drawing given on p. 12, table xxx. of Musschenbroek's *Tentamina Experimentorum Naturalium*, Lugduni, 1731, par. ii.

‡ *Phil. Trans. Roy. Soc.*, vol. lxxii., 1782, p. 305.

ance, and strove to reconcile the discrepancies which were discovered in working it.

As regards date, the physicist who next deserves mention, is Antoine César Becquerel.* His contributions to electro-pyrometry were very noteworthy. In 1826, he used various thermo-couples, especially one of platinum and palladium, and he showed that even two wires of platinum of different manufacture could be employed. He actually measured, with the aid of a thermo-couple of fine wires, the temperatures of different portions of a luminous flame. He also recognized that the behavior of iron is abnormal. His couples were simply joined without solder.

Prinsep† was the first to use an air thermometer with a metallic bulb. He was the Assay Master of the mint at Benares, and appears to have been struck by the necessity for measuring variations in the temperature of the muffle used in assaying. He says the disparity of heat in different parts of the same muffle is greater than might have been supposed, and, in view of the importance of the operation of assaying, he points out that "it would be useful to know every difference in this respect."

Prinsep had already attempted to determine high temperatures by the use of a graduated series of alloys of gold and platinum, a method which is still in use; and he suggested the adoption of an optical pyrometer, in which the relative intensity of light from various sources was measured by interposing plates of brown mica between the eye and the glowing body.

In 1836 we come to Pouillet, whose work Barus justly says is of prime importance. He constructed an air thermometer with a bulb *of* platinum, which enabled him to work at very high temperatures. "He took the first definite steps in radiation-pyrometry by investigating the temperature at which solids glow; in calorimetric pyrometry, by determining the specific heat of platinum between 0° and 1200°; and in thermo-electric pyrometry, by carefully calibrating a thermo-couple of iron and platinum."‡

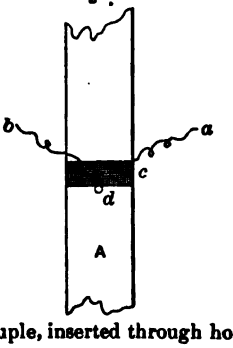
In accepting this tribute to Pouillet's work in thermo-electric pyrometry we must not forget the earlier labors of A. C. Becquerel.

Pouillet's§ paper is interesting reading, but it will be quoted

* *Ann. de Chim.*, vol. xxxi., 1826, p. 371.
† *Phil. Trans. Roy. Soc.*, 1828, p. 79.
‡ Barus, *op. cit.*, p. 28.
§ *Comptes Rendus*, vol. iii., 1836, p. 782.

here for the sake of its incidental references to practical work. He clearly shows that he suspected that gases are absorbed by platinum, and thus anticipated much later work; while, as regards the industrial value of the thermo-couple in pyrometry, he says: "The pyrometer offers the advantage of being a really practical instrument, and its sensibility augments as the temperature rises. When it is graduated by the aid of the air-pyrometer it is suitable for indicating with great exactitude the temperature of any furnace, provided it is below the melting-point of iron." The facts stated in this sentence are, after a lapse of more than half a century, being generally accepted. Joule* saw how useful the thermo-couple would be as an instrument of research, and actually employed a copper-iron one for measuring the heat which is evolved when a bar of metal is subjected to tensile stress. The early use of a thermo-couple for such a purpose is so interesting that a sketch from Joule's paper is given in Fig. 3, which shows the way the thermo-

Fig. 3.



Thermo-couple, inserted through hole in bar.

couple is bound to the test piece. With reference to the use of an iron couple, it may be observed that Edmond Becquerel† appears to have been aware that there is a critical point in iron, for he abandoned the use of the iron-platinum couple because he found that the indications were disturbed between a temperature of 500 and 700°. We now know that a critical point in carburized iron does lie between these temperatures. He finally adopted the platinum-palladium couple, and his determinations of the melting-points of silver (960°) and of gold (1092°) show but little divergence from those now accepted.

* *Phil. Trans*, vol. cxlix., 1859, p. 91.

† *Ann. de Chim. et de Phys.*, vol. lxviii., 1863, p. 49.

Returning to Pouillet's work, it should be observed that the interdependence of the indications afforded by the air-thermometer and by the thermo-couple, is the basis of much work that followed. The air-thermometer and the thermo-couple really afford concurrent and equally trustworthy testimony in the measurement of high temperatures; but the difficulty of correlating this testimony gave rise to the long controversies between E. Becquerel, who used the thermo-couple, and Deville and Troost, who advocated the adoption of the porcelain-bulb air-thermometer. The discussion concluded with the graceful words of the latter physicists:* "Nos nouvelles déterminations de la température d'ébullition du cadmium et du zinc, au moyen des thermomètre à air, sont presque concordantes avec les nombres qui ont été publiés par M. Edm. Becquerel, et cet accord avec ce savant physicien nous donne quelque confiance dans les expériences dont nous publions plus haut les résultats."

Let the reader study the classical work of Deville and Troost, conducted with the air-thermometer between the years 1863 and 1880, and compare it with the admirable researches of Edmond Becquerel; then let the reader turn to the recent paper by Professor Barus† on the calibration of the platinum, iridio-platinum thermo-couple (first used by Tait‡ in 1873), with a porcelain-bulb air-thermometer of refined and elaborate construction§, and it will be evident how greatly scientific progress would have been promoted if the accuracy of the views of A. C. Becquerel and of Pouillet had been verified earlier.

There was much intermediate work of great interest in the period 1863–1880, of which space will not permit a detailed account to be given. It is, however, impossible to be indifferent to the scientific progress which was made in the early part of this critical period in the history of pyrometry.

A picturesque and almost romantic incident is connected with the work of J. J. Waterston, and it has been well described for us by Lord Rayleigh, who found a paper by Waterston in the archives of the Royal Society, in which he clearly enunciated, in pre-Maxwell days, the kinetic theory of gases. I have referred to Waterston because the fortunate circumstance of his having had, as he says, "to graduate a water-thermometer,"‖ appears to have led him to

* *Comptes Rendus*, vol. xc., 1880, p. 777.

† *Phil. Mag.*, 5th Series, vol. xxxiv., 1892, p. 1, and *ibid.*, p. 376.

‡ *Edinburgh Roy. Soc. Trans.*, vol. xxvii., 1873, p. 125.

§ See page 439.

‖ See his paper, *Phil. Mag.*, 4th Series, vol. xxvi., 1863, p. 1.6.

the singularly advanced view that the ultimate molecule, as an integral part of a gas or vapor, is "capable of sub-division." "It is daily becoming manifest," he adds, "that the elementary molecule, although minute beyond conception, is to be studied as a microcosm essentially dynamical in its internal constitution, its apparent statical condition being simply the antagonism of transcendent *vis viva* potents."* He points to the fact that the "forces at the command of the chemist are insignificant in comparison to the heat and pressure with which the elements of matter have to contend in the body of the sun." Surely a very remarkable sentence, since justified not only by Lockyer's work, but by the abandonment of iodine vapor in pyrometry, which followed Victor Meyer's evidence as to its being dissociated at high temperatures.

A new phase in the history of the measurement of high temperatures began with the work of Sir William Siemens, who showed that the variations in electrical resistance of a heated metallic conductor would afford a pyrometric method. The names of Muller, Quincke and Ressig may be mentioned in connection with early work in this direction, but Siemens was the first to demonstrate the practical nature of the method. The first mention I can find of his experiments is given in a letter to Dr. Tyndall, dated December, 1860. Twelve years later, in a lecture delivered before the members of the Royal Institution, Siemens† makes some interesting remarks on the industrial aspect of pyrometry as limited by capabilities of the mercurial thermometer. He said: "When we ascend the scale of intensity we soon approach a point at which mercury boils, and from that point upwards we are left without a reliable guide, and the result is that we find in chemical books on chemical processes statements to the effect that such and such a reaction takes place at a 'dull red,' such another at a 'bright red,' or a 'cherry-red,' or a 'white heat'—expressions which remind one," he adds, "of the days of alchemy rather than of chemical science at the present day." With reference to this it may be observed that if, as Sir William says, technical men were "left without a reliable guide" directly the limits of the mercurial thermometer were passed, it was their own fault. The thermo-junctions proposed by Becquerel and others would have given them trustworthy measurements of high temperatures, but they either lacked knowledge of the sources of information or the will to use the far from complicated appliances at command.

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* *Loc. cit.*, p. 132. † *Proc. Roy. Ins.*, vol. vi., 1872, p. 438.

It is possible that the use of thermo-couples may have been much retarded by Regnault's condemnation of them. He says, in his great treatise on heat: "I must confess that notwithstanding the very numerous and varied experiments which I have made, my researches have met with little success, and I have not been able to obtain a comparable instrument whose indications might at all times inspire confidence." These words must have been familiar to English readers, as they appeared, thus translated, in the *Philosophical Magazine*, vol. xxxvi., 1850, pp. 409–420.

An excellent dead-beat galvanometer, so essential in connection with all pyrometric methods of which electricity is the base, was actually provided by Sturgeon as early as 1836; but metallurgists, who sadly needed a good pyrometer, were either ignorant of the

Fig. 4.

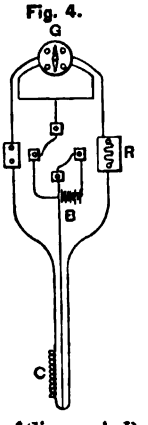


Diagram of Siemens's Pyrometer.

existence of such physical instruments or untrained in their use, and are only now beginning to recognize the necessity for their adoption. The nature of Siemens's instrument may be made clear by the accompanying diagram, Fig. 4. A divided current passes from the battery, B, to a platinum wire, C, coiled round a clay cylinder, and to a resistance-coil, R. At the ordinary temperature, the resistance of the platinum coil is balanced by the standard resistance, R. If, however, the platinum coil be heated, its resistance will be increased, and this increase of resistance, which can be measured in various ways, indicates the temperature of the coil, C. The coil itself may be adequately protected and exposed to temperatures which have been determined by the air-thermometer; the deflection of a suitable (differential) galvanometer, G, will then indicate temperatures

directly. For instance, the temperature at which zinc boils has been determined to be 940° C., and if the coil is heated in the vapor of boiling zinc, the angle through which the galvanometer is deflected marks the temperature of 940° C.

It will have been evident, from what has been already adduced with reference to the work of M. Becquerel and of Deville, that by the year 1880 two main systems of pyrometry had been well established. These depended, respectively, on the use of the air-thermometer and of thermo-couples. Siemens's electrical pyrometer, though its excellence was admitted, was expensive, and confidence in it was not established. The basis of optical pyrometry had been firmly laid, but the measurement of high temperatures by optical methods had not passed into the domain of industrial work.

The publication of the article "Pyrometer" in the last edition of the *Encyclopædia Britannica* in 1886, will enable us to judge what progress had been attained at the period when this important work appeared. In 1886 the author of that article, W. N. Shaw, who is eminently qualified to form an opinion, took a decidedly gloomy view of pyrometry. He concludes his excellent article by suggesting a doubt whether any of the instruments he describes can be easily made to take up the temperature of the body or enclosure under investigation and he points out that "perhaps the most important modern attempts at the development of pyrometry are those connected with the identification of the law connecting the temperature of a body with the amount and nature of the energy which it radiates," "on such attempts depends the possibility of measuring the temperature of a hot body by means of the light it emits" . . . . and he adds, "that at present there is no general agreement among scientific men as to the form the relation takes." In 1886, the year Shaw wrote, the beginnings of very distinct advances in practical pyrometry were made. Callendar* published the first part of the work that was subsequently developed in his well-known paper,† which restored confidence in the electrical resistance pyrometer. In the following year Prof. H. Le Chatelier‡ communicated a paper to the Chemical Society of Paris on the platinum, platinum-rhodium thermo-couple which gave an entirely new and vigorous impulse to thermo-electric methods of pyrometry, as the wires of the thermo-

* *Proc. Roy. Soc.*, vol. xl., 1886, p. 566.

† *Phil. Trans. Roy. Soc.*, vol. clxxviii., 1887, p. 161.

‡ *Bull. Soc. Chim.*, Paris, vol. xlvii., 1887, p. 2. *Journal de Physique*, 2ième Série, vol. vi, 1887, p. 23.

couple he employed take up the temperature of the locality in which it is placed with astonishing rapidity.

The nature of Sir William Siemens's instrument has already been shown in Fig. 4. Its usefulness was so widely recognized that a committee of the British Association was appointed to report upon it. The result of the inquiry rather tended to shake confidence in the instrument as it was shown that it was liable to changes of zero. Mr. H. S. Callendar* has, however, done much to prove that, with certain precautions, the method on which it is based may be rendered very trustworthy. He winds the platinum wire on a plate of mica, excludes reducing gases as the committee suggested by enclosing the coil in a tube of doubly-glazed porcelain, and uses a zero method of measuring the currents with the galvanometer. Fig. 5 represents somewhat diagrammatically, the arrangement of the apparatus.†

Fig. 5.

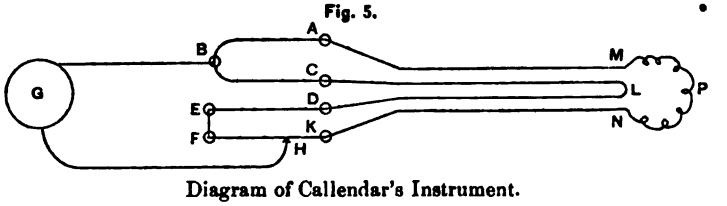


Diagram of Callendar's Instrument.

A B, B C, are equal resistances, forming the arms of the balance. The battery is connected at A and C, and one terminal of the galvanometer, G, at B. D E represents a set of resistance coils, which together with the resistance, A B, and B C, may be supplied by an ordinary box of coils of the "post-office" pattern. F K represents a straight bridge-wire, with a divided scale attached. The other terminal of the galvanometer is connected to the contact-piece, H, which slides along this wire. The leads, A M, K N, from the pyrometer coil, P, are connected to A and K; and the compensating leads, C L, L D, the resistance of which is equal to A M, K N, are connected to C and D. These four leads may be of any convenient length; they are symmetrically arranged, so that corresponding parts are always at the same temperature. When the balance is found by inserting suitable resistances in the arm, D E, and sliding the contact-piece, H, it is plain that, since the resistances, A B, B C, are equal, the resistance of the pyrometer and its leads,

* *Loc. cit.*

† *Phil. Magazine*, 5th ser., vol. xxxii., 1891, p. 104, and vol. xxxiii., 1892, p. 220.

together with that of the length, H K, of the bridge-wire will be equal to the remaining portion, F H, of the bridge-wire, together with the coils, D E, and the compensation, C L, L D. Thus, the changes of the resistance of the pyrometer-leads, A M, K N, are compensated by the equal changes in the leads, C L, L D, and the resistance of the pyrometer-coil itself is directly given by the sum of the coils, D E, and the reading of the bridge-wire. The resistance of a centimeter of the bridge-wire, F K, is made to correspond to such an increase of the resistance of the pyrometer coil, P, as is produced by a rise of 1° C. The contact key, H, slides along this wire, and the galvanometer can easily be made sensitive to one-hundredth of a centimeter of this bridge-wire; so that one-tenth of a centimeter, which corresponds to one-tenth of a degree, can of course, be measured with certainty. The author has worked for several days at the Royal Mint with Mr. Callendar, and is satisfied, that at temperatures exceeding that of bright redness, the comparative readings are accurate to one-tenth of a degree. This would have been considered impossible a few years ago, and the statement will, perhaps, be received with some incredulity. Evidence, however, leads to the belief, that in the measurement of a "white heat," degrees of value similar to those of the ordinary mercurial thermometer are still employed.

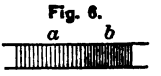
As has been already stated, Professor H. Le Chatelier, of the École des Mines, Paris, advocated the use of platinum, in conjunction with the platinum alloyed with 10 per cent. of rhodium. The author first adopted this couple in 1889, and has since constantly used it, in conjunction with a photographic recorder, which he devised for the purpose of an investigation which was entrusted to him by the Institution of Mechanical Engineers, London. In its latest form the instrument consists of two wires, one of the metal, and the other of the alloy mentioned above, simply twisted at their ends or soldered with gold, and connected with a dead-beat galvanometer of about 200 ohms resistance. The Deprez and D'Arsonval form of galvanometer, particularly the latest type of this intrument, is admirably adapted for use with this thermo-couple.

The spot of light from it is usually received on a translucent graduated scale, and the observations recorded by eye; but a photographic method was employed as early as 1887 by H. le Chatelier* in connection with his thermo-couple. It consisted in allowing the

* *Comptes Rendus*, vol. civ., 1887, p. 1443.

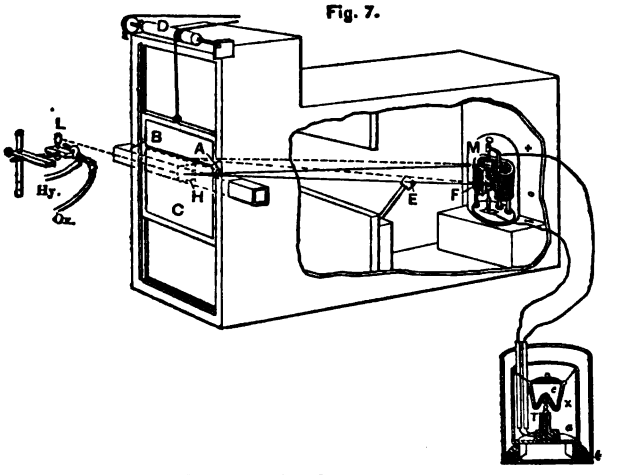
image of induction sparks, produced at regular intervals of time, to fall on a narrow fixed sensitized strip of glass. If the temperature to which the thermo-couple is exposed is rising or falling at a uniform rate, the photographic images of the sparks will be equidistant as at *a*, Fig. 6, but if there is at any moment an arrest in the rise

Fig. 6.



or fall of the temperature the images of the sparks will then be closer together, as at *b*. The distance between the individual lines affords a method for measuring the rate at which a thermo-couple receives or loses heat from any hot locality or substance in which it may be placed. It will be obvious that by confining the image of the mirror to a minute spot, and by moving the sensitized plate at a uniform rate a time-temperature curve may be traced by the agency of photography. Such curves are often very beautiful, and I have elsewhere shown* that they may yield results of much importance.

Fig. 7.



Le Chatelier Pyrometer.

The arrangement,† which is shown in Fig. 7, consists of a galvnometer of the Deprez and D'Arsonval type enclosed in a large camera ; a fixed mirror, F, is placed below the movable mirror, M, of the galvanometer, so that the light from the lime cylinder, L, reflected

* *Pro. Roy. Soc.*, vol. xlix., 1891, p. 347 ; vol. l., 1892, p. 367.

† *Pro. Inst. of Mech. Eng.*, 1891, p. 543; 1893, part ii., p. 102.

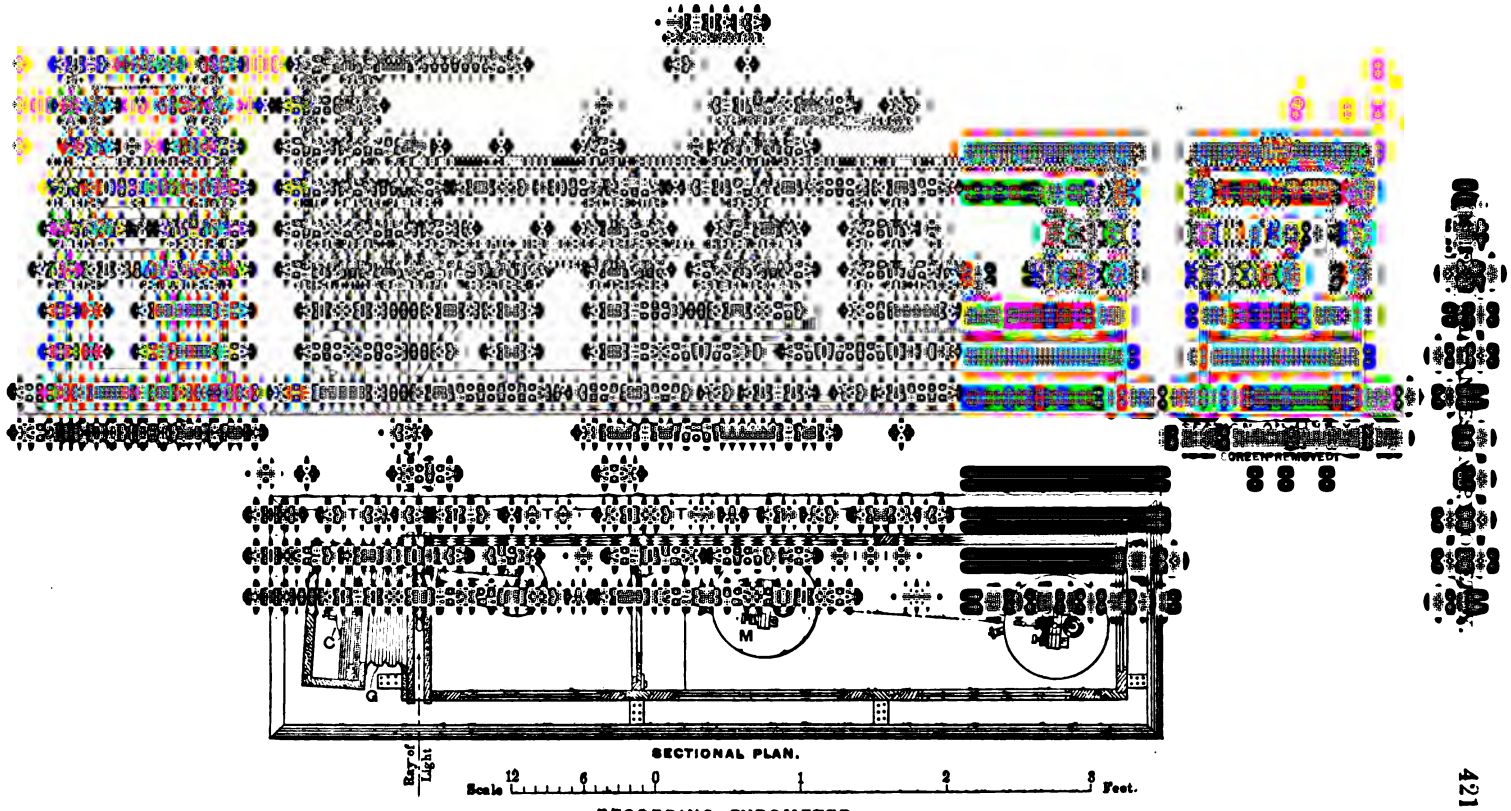
in the mirror, H, passes to both mirrors, F and M, and is reflected in the direction of a fine horizontal slit, A B; behind which a sensitized photographic plate, C, is drawn vertically past the slit, by means of gearing, D, driven by clockwork. The ray from the fixed mirror is interrupted periodically by the vane, E, and a beaded datum-line is given, which enables any irregularity in the advance of the plate to be detected.

The amount of divergence, from its datum-line, of the spot of light reflected by the movable mirror at any given moment, bears a relation (which can readily be found by calibration) to the temperature to which the thermo-couple, X, is heated; and the variations of temperature are denoted by a curve which is the resultant of the upward movement of the plate and the horizontal movement of the spot of light. A crucible, *c*, which may be filled with molten metal, is provided with a tubulure, T, for the insertion of the thermo-couple. The crucible is suspended by wires in a double jacket of tin-plate, *a b*.

The author is satisfied that this thermo-couple can afford trustworthy results, accurate to 1°, at temperatures of over 1000° centigrade. One important feature of the appliance is the minuteness of the space occupied by the thermo-couple, which may be suitably protected and inserted in the midst of a very small mass of metal. The pyrometer is calibrated by exposing the thermo-couple to certain known temperatures, such as the solidifying points of salts or metals. There is no difficulty in recognizing the melting or solidifying points, for as the mass passes from the solid to the fluid state, the temperature remains constant for a brief period, the duration of which depends on the amount of material operated upon and its latent heat of fusion, the result being that the spot of light from the galvanometer will be arrested, and the position on the scale at which it stops marks the temperature to be determined.

A detailed drawing of a more elaborate form of this appliance is given in Plate I.

The appliance consists, as is shown in this plate, of a camera about 5 feet long, in which a galvanometer may be placed in either of two positions according to the range of temperature to be observed. This camera has three doors, and is made separate from the portion of the apparatus which contains the moving photographic plate, C. The two parts are connected by a flexible leather "bellows" junction, G, the object being to enable the plane of the sensitized plate to be adjusted at right angles to the rays of light from the galvanometer



RECORDING PYROMETER.

mirrors, F and M. Inside the camera is a focussing-tube, T, containing a lens, L, which receives the light from the mirror, H, and transmits it to the mirrors, F and M. One of these mirrors, M, is movable, and is carried by the coil of the galvanometer, while the other, F, is carried upon an adjustable arm fixed to the supports of the galvanometer, its function being to send a ray of light from the mirror, H, to the slit, A B, and thus to trace a datum line as the photographic plate travels upward. The temperature is recorded by the variations in the position of the spot of light received from the mirror, M. There is a screen, S, to cut off light reflected from the brass work of the galvanometer. The end of the tube, T, is provided with an adjustable brass slit, O, by means of which the width of the photographic traces on the plate may be varied. The mirror, H, is mounted on a block, which can be adjusted so that external light may be received from either side. The focussing of the lens, L, may be effected from outside the camera. Plug connections are provided at the top of the instrument, and the wires, *a*, *b*, connect the galvanometer with a thermo-couple, J, placed in the furnace or other source of heat. The photographic plate is secured to its carrying-slide, C, by means of little cams, and this carrier is enclosed in a case, K, provided with a light-tight door, I. The case, K, is held in position by a pin, P. The connection of the photographic plate with the driving clock is shown at D. It may be mentioned that the galvanometer stands on three plates, which provide the well-known combination of the hole, slot and plane, to ensure steadiness. If the sensitized plate be replaced by a revolving drum bearing photographic paper, it will be obvious that a time-temperature curve of considerable length can be readily obtained, and such curves afford convenient records of the variations in the temperature of any furnace or other source of heat in which the thermo-couple, J, may have been placed.

The service this instrument has rendered in connection with metallurgical investigation I have described elsewhere.* Its use not only for measuring, but actually recording the temperatures employed in conducting industrial operations was soon apparent.

The history of the application of the thermo-couple with a recording-instrument for use in works is as follows: The first public demonstration in England of the advantages of Le Chatelier's thermo-junction was given by the author† of this paper at the

* *Loc. cit.*

† *Nature*, vol. xli., 1890, pp. 11 and 32.

meeting of the British Association held in Newcastle in 1889, and Sir Lowthian Bell was so forcibly impressed with the desirability of applying it to the measurement of temperatures of blast-furnaces that he soon adopted it at the Clarence Works. In 1892 Mr. Charles Bell * communicated to the Cleveland Institution of Engineers a very interesting paper, in which some curves were plotted, giving the results of measurements of the temperature of the hot-blast supplied to certain furnaces. He also described a novel application of the thermo-junction to the indication of the *time* at which the successive charges were introduced into the furnace. For this purpose a thermo-junction, connected with a suitable galvanometer, was placed in the "down-comer" of the blast-furnace, and as the lowering of the charging-cone or bell was attended by the admission of cold material, the consequent lowering of the temperature could be observed on the galvanometer scale, and enabled the time at which the charging had been effected to be noted by an attendant.

As regards recording the temperature employed in conducting metallurgical operations, photography had already done excellent service in affording the author of this paper a means of observing changes in the behavior of alloys during thermal treatment. It was evident that it could also be employed for autographically recording the changes of temperature either in the hot-blast or in any locality in which the thermo-couple might be placed. The recording pyrometer about to be described was accordingly devised.

In order to provide an instrument which could be used for recording the temperatures of furnaces or other appliances used in works, the apparatus shown in Fig. 7 had to be modified.

1st. It was necessary to simplify the portion of the apparatus which receives and records the movement of the spot of light; and

2d. To avoid the necessity of shifting a single thermo-couple from furnace to furnace by placing separate thermo-couples in each furnace, provision being made for placing each center of heat, in turn, in connection with a single galvanometer and recording instrument.

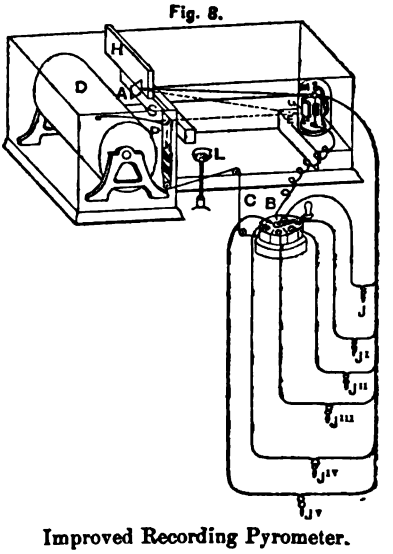
The first object has been attained by replacing the moving plate, C, Fig. 7, of the original apparatus by a brass cylinder, six inches in diameter, moved, at the rate of a single revolution in 24 hours, by clockwork contained within it. This cylinder has sensitized paper fixed round it, and the portion of the camera which contains

* *Proc. Cleveland Inst. of Engineers*, 1892.

it can be detached from the rest of the appliance and removed to the dark-room for the development of the record imparted to the paper.

The apparatus is shown in Fig. 8. In it provision is made for placing any one of six centers of heat J to J^{v}, such as hot-blast stoves or furnaces, in connection with the galvanometer, and for obtaining within the period of the revolution of the cylinder a record of the temperature of any one or of all the six sources of heat. The record of a number of furnaces would, however, be intermittent, the duration of the test in any particular case being subject to the will of the operator, who, by merely turning a handle, determines which particular furnace shall be placed in connection with the galvanom-

Fig. 8.



Improved Recording Pyrometer.

eter and the length of time which shall be devoted to its test. This shifting of the electrical contact from furnace to furnace could readily be effected by clock-work, and the tests would then be entirely dependent on manual adjustment.

The drawing shows the method adopted for indicating which particular source of heat is in connection with the galvanometer. If, for instance, No. 1 furnace is under examination, light from the lamp, L, passes through a single slit and traces a single continuous datum line. The line traced by the light from the galvanometer-mirror, M, is more or less removed from this datum, and the position of any given point depends on the temperature to which the

thermo-junction is raised at the moment the point is photographed. In the case of, say, No. 4 furnace the datum line would be produced by allowing the light to fall through four fine slits, and a quadruple series of fine parallel lines would be produced, the lowest line of the series being the true datum.

The apparatus* consists of a box or camera, which is drawn as if it were transparent. The galvanometer, G, may be connected with each of the six thermo-couples (J to J') in turn. Each of these thermo-couples is placed, suitably protected, in a furnace, the arrangement shown in Fig. 8 merely indicating the methods of making the connections of the six thermo-junctions with the galvanometer by means of the switch, B. The handle of this enables either of the thermo-couples to be connected with the galvanometer. The light from the gas flame, L, falls on to a mirror, A, and passes from it to the movable galvanometer mirror, M, and is reflected from it through a fine horizontal slit to the drum, D. This drum contains the clock-work which causes it to revolve once in twenty-four hours. Light from the mirror, A, also falls on to a fixed mirror, E, placed below the movable mirror of the galvanometer, and this enables a datum line to be traced on the sensitized photographic paper by which the drum is covered. The temperature to which any given thermo-couple is raised will be indicated by the position of the line which is traced on the paper by the spot of light falling from the mirror, M.

The *number* of the particular furnace under examination is indicated as follows: The switch, B, is connected by a cord, C, with a strip of metal, F, and this strip, which is supported by a spring, S, bears a number of fine horizontal slits. If, for instance, No. 3 furnace is under examination, light from the lamp, L, will fall through a fine *horizontal* slit in the wall of the box containing the drum, and through *three* slits in the vertical strip, P. A triple continuous datum line will be photographed on the drum as long as connection is maintained with No. 3 furnace. If No. 2 furnace is being tested, the datum line will be double, while if the furnace is No. 1 the line will be single.

A slide, H, may be screwed down so as to exclude light from the portion of the camera which contains the drum, and this portion may then be removed to the dark room where the record as traced on the sensitized paper is developed.

* *Jour. Iron and Steel Inst.*, No. 2, 1892, p 33; No 1, 1893, p. 112.

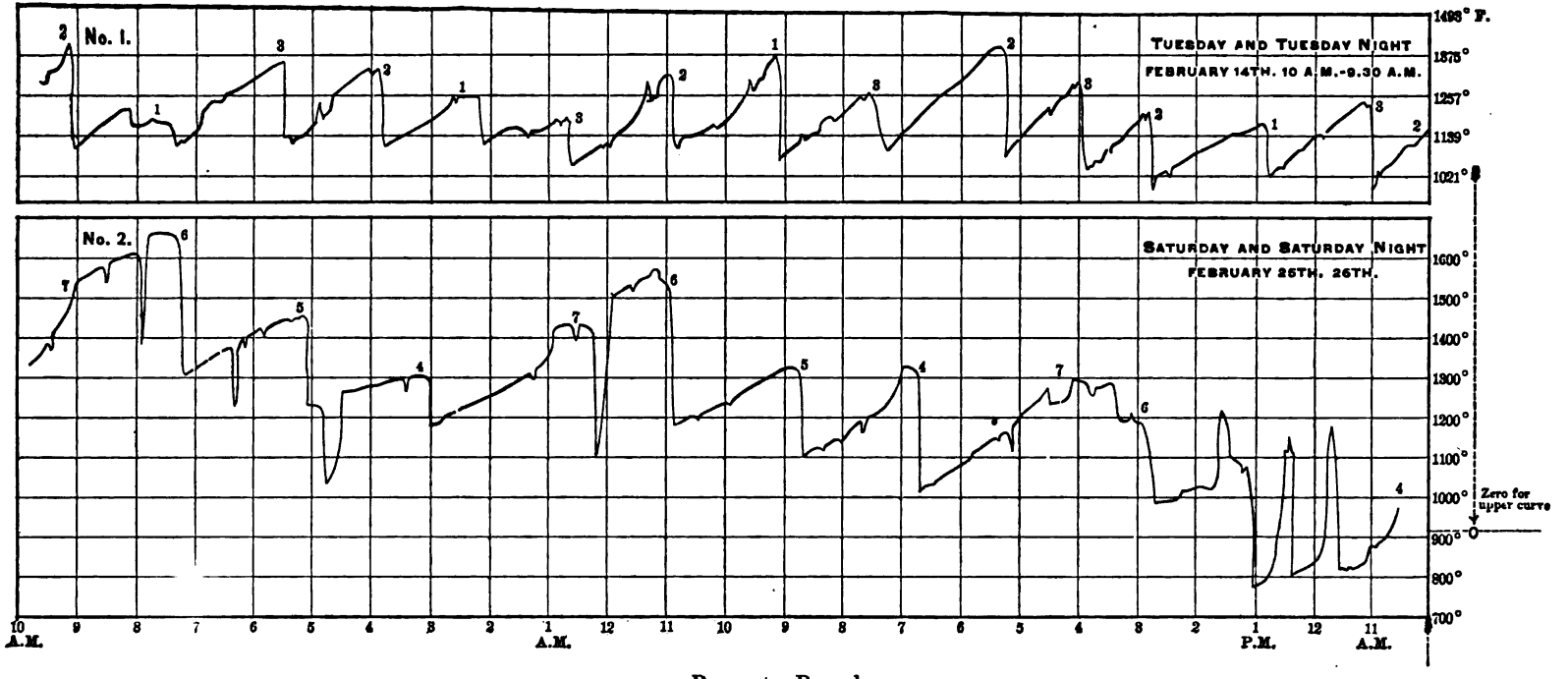
The anticipation that the "recorder" would prove to be a valuable adjunct of an iron and steel works was amply justified, as the curves obtained by its aid will show. The following details respecting them are perhaps somewhat beyond the scope of this paper, but it is intended to be an eminently practical one, and a brief digression to show the value of a continuous record in a particular set of conditions may not be out of place. The case chosen is the measurement of the temperature of hot-blast in iron-smelting. The Fahrenheit scale is adopted as the one that is employed in English works.

Plate II. represents a record for twenty-three and a half hours of the temperature of the hot-blast supplied to a furnace by a series of stoves, numbered respectively Nos. 1, 2, 3. It is a typical record, and, as it represents an excellent sample of careful and successful gas-firing, it may be well to describe it in some detail.

It will be seen that the record begins near the top right-hand corner, and shows that the temperature of the blast contributed by No. 2 stove (at 10 A.M. on the 14th of February) had an initial temperature of 1160° Fahr. At the end of an hour the temperature of the blast had fallen to 955° Fahr., and the gas-man considered that the time had arrived for effecting the connection with a fresh stove, No. 3. As will be seen from the record, this stove contributed blast at an initial temperature of nearly 1230° Fahr., and the temperature fell in the course of one hour and fifty minutes to 1020° Fahr., when the blast from No. 1 stove was introduced into the horseshoe main. Inspection of the curve will show the successive variations of temperature. The record viewed as a whole, shows that the temperature never rose above 1400° Fahr., or fell below 950° Fahr. This record shows good, conscientious, careful firing, such as should ordinarily be obtained in works. Complications are, however, introduced by untoward accidents, which unfortunately, will happen, and diagram No. 2, Plate II., has been specially selected as indicating the existence of a set of conditions which presented much difficulty.

The record refers to stoves Nos. 4, 5, 6, and 7, and begins at 10.30 A.M. on February 25th. For 2½ hours the temperature of the blast rapidly varied between 1180° and 730° Fahr., and it is evident the working of the furnace showed that it had a "scaffold," and that cold or "coddled" blast was being freely introduced. This state of things continued for three hours longer, when the conditions became more equable. It will be observed that when No. 6 stove

PLATE II.



Pyrometer-Record.

is resorted to, the temperature suddenly rises, although it is evident that cold-blast was also being used. Stove No. 6 soon gave place to stove No. 7, and the turn of No. 6 did not come again until 7 hours later, when its temperature proved to be very high (1570° Fahr.), and the same fact was recorded when No. 6 stove was again used at 7.10 A.M. on the following morning. A consideration of this unsatisfactory record led to the view that No. 6 stove must be receiving a supply of hot, and not entirely of cold air, during the period in which it was being heated up. It was found, on investigation, that the valve of No. 5 was leaky, and that hot air from the other stoves could find its way into it—an accident which was of course soon remedied.

The importance of maintaining a constant temperature of blast is manifest. The ratio that the reducing actions bear to the fusing ones varies with the temperature of the blast, and if a furnace has been steadily working at a given rate it will be prejudicial to suddenly increase the activity of reduction in the cooler parts of the furnace, as they would then contribute reduced iron and pasty slag at a greater rate than that at which they could be disposed of in the zone of fusion. The effect of a rapid increase in the temperature of the blast influences the reduction zone more rapidly than it does the zone of fusion; hence the tendency of the furnace to choke if the temperature of the blast is suddenly augmented.

It appears to be recognized that an unduly high temperature of the blast is favorable to the formation of scaffolds, and the introduction of cold-blast is known to remove them. Hence it is desirable not only to be able to measure the temperature of the blast, but to be able to observe the temperature at any given moment. In recent forms of the "recorder" a subsidiary mirror diverts the ray of light from the drum, and throws it on to a divided transparent scale on the top of the camera, so that a direct observation of the temperature can be made without seriously interrupting the progress of the photographic record. By watching the progress of the record it is frequently possible to diminish the amount of fuel charged into the furnace, and thus to effect economies which may, it is to be hoped, attain considerable proportions.

If, in a given set of conditions, 13 units of carbon are required to smelt a ton of iron, with the temperature of blast at 880° Fahr., 16 units of carbon will still be required if the temperature be 1680° Fahr.—so that there is clearly a limit to the advantages of heating the blast. A large blast-furnace, smelting iron, may have

a capacity of 35,000 cubic feet, and of this 20,000 cubic feet is in brilliant ignition, and presents the largest mass of fuel in rapid combustion which is employed in any single industrial operation. In view of all the complex problems involved in the working of a blast-furnace, the solution of which depend mainly on thermal conditions, it is truly remarkable that hitherto there has been no sustained effort to accurately measure and record the temperature of the blast—this being the factor of paramount influence, and the one that can be most readily controlled.

The chief advantages which may be claimed for the appliance are as follows:

1. A check is placed on the gas-men, and, to a less extent, on the men at the furnace-top.

2. Inferences may be drawn as to the conditions which prevail in the interior of the furnace.

3. Accurate information may be gathered as to the time of reversal of the valves, and of casual admission of cold-blast.

4. Certain indications, afforded by the curves, show that changes have been effected in the accessories of the blast-furnace, such as the removal of the tuyeres, alterations in breast-plates, etc.

It should be observed that the appliance is popular with the work-people, who find that regularity in conducting the details of the various operations means increased output, and, moreover, the gas-men recognize that it is to their advantage to have an autographic record of the way in which they have done their work.

Bearing in mind that this paper is limited to the consideration of such pyrometrical methods as have taken a place in industrial practice, there are at least four other methods which have to be dealt with. These are:

1. Calorimetric methods.
2. Optical methods.
3. Pyrometric alloys.
4. Barus's method, depending on the viscosity of gases.

As regards calorimetric methods, I would only observe that the admirable researches of M. Violle * have shown how trustworthy and accurate the results obtained by these methods really are. It is, moreover, mainly his calorimetric work which has fixed the points of fusion of the precious metals, and the data so obtained has

* *Comptes Rendus*, vols. lxxxv., 1877, p. 543; *ibid.*, vol. lxxxix., 1879, p. 702; vol. xcii., 1881, p. 866; *Phil. Mag.*, 5th series, vol. viii., 1879, p. 501, and vol. xiii., 1882, p. 147.

enabled us to graduate other forms of pyrometer. M. Violle has even determined by a calorimetric method * the temperature of the electric arc of 400 amperes and 85 volts by detaching a button of incandescent carbon from an arc light and catching it as a calorimeter; he finds the temperature to be 3000° for the hottest part of the arc, which must be close to the volatilizing point of carbon.

From the point of view of practical use, the rudimentary forms of calorimetric appliance employed in works are too well known to need description. At the best they only yield results of approximate accuracy and are often very untrustworthy.

The method of pyrometry based on the use of alloys of which the melting-points have been determined was devised by Prinsep in 1827, as has already been stated. It is a useful method for ascertaining approximate temperatures. Alloys of the precious unoxidizable metals must be employed, and I am informed that Messrs. Roesler, of Frankfort, prepare a series of such alloys which are said to be very trustworthy. I have often used such a series (silver-gold and gold-platinum) with advantage, and, nearly twenty years ago, attempted to register by an electrical method the order of fusibility of such alloys. The method consisted in allowing the alloy, at the moment of fusion, to complete an electrical circuit and, by depressing one of a series of levers, to record the time at which the fusion occurred, on a moving sheet of chemically prepared material. The method was successful but is too cumbersome and difficult for ordinary use.

Any attempt to deal fully with optical methods would demand far more space than the limits of this paper would admit. I shall, therefore, add but little to what has already been adduced in a paper which I read last year before the Institution of Civil Engineers. † Even a brief account of the history of optical methods, which would include references to the honored names of Pouillet, Ed. Becquerel, Crova, and Violle, is far too complex to be dealt with here.

As regards practical work it may, however, be stated that M. Crova ‡ actually employed his spectro-pyrometer for industrial work, and measured the temperature of certain furnaces at the Creusot Works.

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* *Comptes Rendus*, vol. cxv., 1892, p. 1273.

† *Pro. Inst. Civil Eng.*, vol. cx., 1892, p. 152.

‡ *Comptes Rendus*, vol. lxxxvii., 1878, pp. 322 and 979. *Ibid.*, vol. xc., 1880, p. 252. *Ibid.*, vol. xcii, 1881, pp. 36 and 707. *Ibid.*, vol. cxiv., 1892, p. 941.

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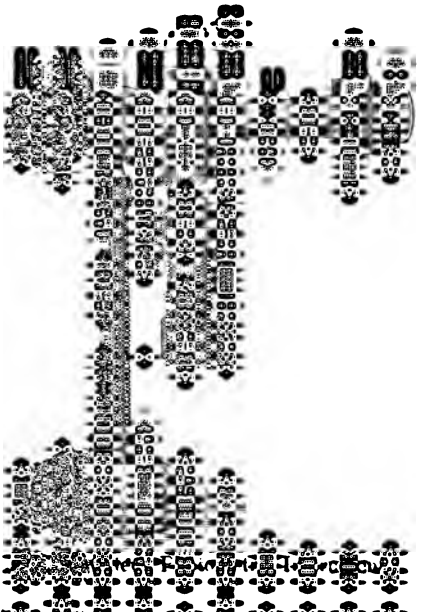

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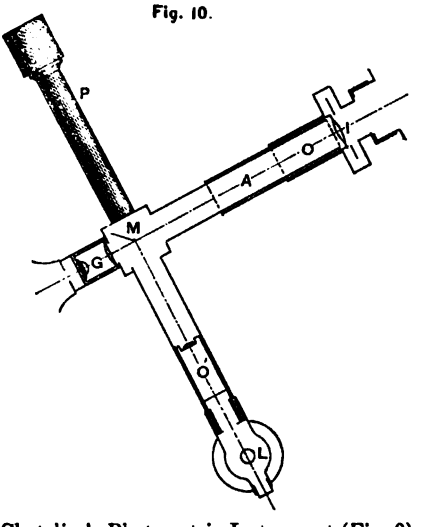
Electrique, No. 7, 1892,

regulated by three screws at C, Fig. 9, so that the luminous image of the lamp, and that of the object to be measured, are brought into juxtaposition, being divided by the edge of the mirror.

The photometer depends upon the adjustment, to the same brightness, of two images; one being that of the flame of a standard lamp, and the other that of the object whose temperature is to be determined. The adjustment is made by means of a diaphragm formed of two plates, each with V-shaped notches opposite to one another. The two plates can be moved past one another by turning a milled head, D, and in this way a square aperture of variable size is formed;

Fig. 10.



Le Chatelier's Photometric Instrument (Fig. 9).

which, being placed in front of the object-glass, O, of the telescope, controls the amount of light admitted from the luminous object.

A divided scale, *I*, is attached to one-half of the diaphragm, and a pointer to the other, and this gives directly a linear measurement, *n*, of the aperture.

Let n' be a measurement, when the image of an object of unit brightness (a candle-flame, for instance) is matched to that of the standard lamp; and n the measurement, when another object is matched in place of the candle. Since the eye-piece has a red glass within it, only red rays pass to the eye for measurement, and the intensity, *I*, of these red rays emitted by the second object, as compared with those from the candle, will be given by the equation:

$$I = \left(\frac{n'}{n}\right)^2$$

But, if the two objects are not at equal distances from the instrument, the intensity will be apparently less for the more distant one, in the ratio $\left(\frac{f}{f'}\right)^2$, where f and f' are the focal lengths (given on the tube A) of the two objects; hence,

$$I = \left(\frac{n'}{n}\right) \times \left(\frac{f}{f'}\right)^2$$

As has been already stated, the great differences of intensity which have to be measured occasionally render it necessary to absorb some of the rays from the object or from the standard lamp, as the case may be. This is done by inserting neutral-tinted glasses in suitable holders, either at E or O'. Let N' be the linear measurement of the aperture, when the luminous object, shaded by a neutral-tinted glass, is matched with the standard lamp, and let N be a similar measurement when the same object is unshaded.

Then the coefficient of absorption of the glass, K, will be given by the equation

$$K = \left(\frac{N'}{N}\right)^2$$

and, when p thicknesses of the neutral glass are before the object, whilst the standard lamp is left unshaded,

$$I = \left(\frac{n'}{n}\right)^2 \times \left(\frac{f}{f'}\right)^2 \times K^p$$

On the other hand, for measuring very low temperatures, when the standard lamp is shaded by p thicknesses of glass, and there are no glasses before the diaphragm, the formula becomes

$$I = \left(\frac{n'}{n}\right)^2 \times \left(\frac{f}{f'}\right)^2 \times \left(\frac{1}{K}\right)^p.$$

the index p being required because each glass cuts off a fraction of the light received by it.

Experiments indicate that the change in intensity of the red rays from a body of temperature T is approximately given by the equation,

$$I = 10^{6.7}\, T^{-\frac{3220}{T}},$$

where T is reckoned from absolute zero, so that $T = (t\,°C. + 273)$, t being the actual reading of the thermometer. This formula has been used to calculate the numbers given in the following table:

Temperature Centigrade.	Intensity of red rays.
600°	0.00008
800°	0.0046
1000°	0.078
1200°	0.64
1400°	3.35
1600°	12.9
1800°	39.0
2000°	93.0

The unit intensity being that of the axial zone of the flame of a standard candle.

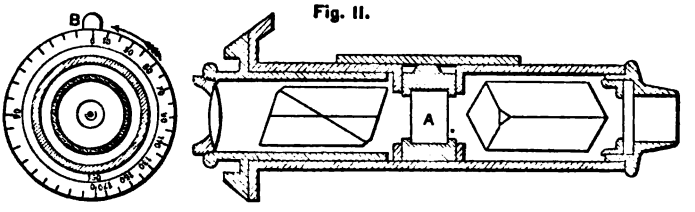
In one instrument, where n' (the reading obtained with a candle flame as a luminous object) was 5.2, and $\frac{1}{K}$ had the value $\frac{1}{25}$, the following figures were obtained by Prof. Le Chatelier:

Temperature.	One glass before standard lamp.	No neutral glasses.	One glass before diaphragm.	Two glasses before diaphragm.
Centigrade. 700 deg.	39.5	.....	.....	.....
800 "	15.2	.....	.....	.....
900 "	7.4	.....	.....	.....
1000 "	3.8	19.2	.....	.....
1100 "	.....	10.8	.....	.....
1200 "	.....	6.7	.....	.....
1300 "	.....	4.2	21.2	.....
1400 "	.....	2.7	13.8	.....
1500 "	.....	.....	10.1	.....
1600 "	.....	.....	7.4	.....
1700 "	.....	.....	5.6	.....
1800 "	.....	.....	4.3	21.5
1900 "	.....	.....	.....	17.0
2000 "	.....	.....	.....	13.8

But, inasmuch as the emissive power of different bodies for red rays is not the same under like conditions as to temperature, it will be doubtless preferable to calibrate the instrument directly by comparing it with a little mass of platinum or of oxide of iron, which can be maintained at known temperatures as measured by a thermo-couple.

There is another optical instrument, the pyrometer devised by Messrs. Nouel and Mesuré, and used by the author for some years in the laboratory of the Royal School of Mines. It consists of a quartz plate, A (Fig. 11), placed between two Nicol prisms, an arrangement that renders it possible to suppress at will the radiations

Fig. 11.



Optical Pyrometer of Nouel and Mesuré.

of any particular part of the spectrum by simply rotating one of the Nicol prisms. If a hot body be observed through the instrument, and the prism be rotated by means of the divided head B, the red color of the body will be seen to change to yellow, then to green, and finally to blue. The angle of rotation necessary to extinguish the red color varies with the temperature and serves as a measure of it; but the difficulty of remembering the precise tint by which the instrument was calibrated, prevents a high degree of accuracy from being attained in its use.

It may be well to give the results of actual observations with a view to show the importance of being able to measure high temperatures with special reference to the work of the engineer. It is evident that the advantages of measuring and controlling the temperatures at which industrial operations are conducted, are more apparent on the metallurgical side of engineering practice than on any other; but, apart from metallurgy, there are many problems in the solution of which pyrometry is of much service. The unaided eye, even of a trained and skilful workman dealing with a special set of conditions with which he is familiar, is, probably, a far less trustworthy guide than it is often supposed to be; for, in estimating the temperature of a furnace, or that of a glowing mass of metal, much

will depend upon the relative brightness of the illumination of the surrounding space.

Some measurements made by the optical pyrometer of temperatures employed in conducting industrial operations will now be given:

Gold-Melting, Royal Mint.

	Degrees Centigrade.
Temperature of standard alloy, pouring into moulds,	1180
Temperature of standard alloy, pouring into moulds (on a previous occasion, by thermo-couple),	1147
Annealing blanks for coinage, temperature of chamber,	890

Silver-Melting, Royal Mint.

Temperature of standard alloy, pouring into mould,	980

Open-Hearth Furnace, Woolwich Arsenal.

Hot gases in interior of melting-chamber,	about 1800
Temperature of steel, 0.3 per cent. carbon:	
Pouring into ladle,	1700
Pouring into moulds,	1700
Pouring into moulds at end,	1650

Ten-Ton Open-Hearth Furnace, Woolwich Arsenal.

Temperature of steel, 0.3 per cent. carbon, pouring into ladle,	1645
Temperature of steel, 0.3 per cent. carbon, pouring into large mould,	1580
Reheating furnace, Woolwich Arsenal, temperature of interior,	930
Cupola furnace, temperature of No. 2, cast-iron pouring into ladle,	1600

It is, of course, useless to attempt to deduce the temperature of a heated space, such as the interior of a reheating furnace, from the radiations of an object which has been newly placed in it, and has therefore not had time to become thoroughly heated.

Professor Le Chatelier* had previously measured the temperature attained in conducting some familiar operations, and as the results obtained by him are, in the case of certain industries, entirely at variance with the estimations which have hitherto been made, it may be of interest to quote a few of them:

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* *Comptes Rendus*, vol. cxiv., 1892, p. 470.

Bessemer Converter (Six Tons Capacity).

	Degrees Centigrade.
Pouring of the slag,	1580
Pouring of the steel into ladle,	1640
Pouring of the steel into mould,	1580
Reheating furnace,	1200
Ingot under the hammer,	1080

Siemens-Martin Open-Hearth Furnace.

Gas:	
Temperature of gas on leaving generator,	720
Temperature of gas on entering regenerative chambers,	400
Temperature of gas on leaving regenerative chambers,	1200
Temperature of air on leaving regenerative chambers,	1000
Temperature of products of combustion approaching the chimney,	300
Metal (about 0.3 per cent. carbon):	
Temperature at end of fusion of pig-iron,	1420
Temperature at "fining" of the steel,	1500
Temperature at pouring of the steel into the ladle { beginning,	1580
Temperature at pouring of the steel into the ladle { end,	1490
Temperature at pouring of the steel into the mould,	1520

Regenerative Furnace for Crucible-Steel.

Temperature in the spaces between the crucibles,	1600

Blast-Furnace, Smelting Gray Pig.

Opening in front of the tuyere,	1930
Tapping the pig { beginning,	1400
Tapping the pig { end,	1570

Siemens Furnace, Used for Melting Glass.

Furnace,	1400
Melted glass,	1310
Annealing the bottles,	585
Furnace for hard porcelain, end of the "baking,"	1370
Hoffmann kiln (brick-burning),	1100
Temperature of incandescent electric lamps,	from 1800 to 2100

There is yet one other method which is very ingenious and possesses great simplicity. It was devised by Prof. Barus,* who has done so much for pyrometry. It depends upon the fact that when a gas flows through a capillary tube or through a fine orifice the amount which passes in a unit of time, under a definite pressure, depends upon the temperature, or as Barus points out, "the rate at which transpiration takes place varies inversely as the absolute tem-

* *U. S Geol Survey, Bulletin* No. 54, 1889, p. 239.

perature of the gas as well as inversely as its viscosity." The reader must refer to the original monograph for the description of this simple method of measuring high temperatures.

It has actually passed into the domain of practice, or reference would hardly have been made to it in this paper, and we may fairly claim it as a practical process, as it has, I believe, been employed by the Compagnie du Chemin de Fer d'Orleans, though I have not been able to obtain any statements as to the results. The platinum tube Barus employed was about 0.5 mm. in diameter. In its simplest form the pyrometer is a short tube, but it may be of considerable length coiled into a helix. It is hoped that more will be heard of this method as its distinguished author* considers that when "interpreted by the Poiseuille-Meyer formula, transpiration data must enable us to measure temperature absolutely, over a wider thermal range, and with greater convenience and accuracy than is now possible with any other instrument."

One very important question must now be considered. The various forms of pyrometer afford certain indications at very high temperatures; are these indications capable of accurate expression in ordinary degrees, that is, are the degrees measured at a white heat comparable with the degrees of the ordinary thermometer? In attempting to answer this question it must be remembered that pyrometers are graduated by the aid of certain "fixed points," boiling points or fusing points, and the following list gives a sufficient number of such fixed points, which have been established by concurrent evidence of various kinds.

Degrees Centigrade.	
100,	Boiling point of water.
326,	Melting point of lead.
358,	Boiling point of mercury.
415,	Melting point of zinc.
448,	Boiling point of sulphur.
625,	Melting point of aluminum.
665,	Boiling point of selenium.
945,†	Melting point of silver.
1015,	Melting point of potassium sulphate.
1045,	Melting point of gold.
1054,	Melting point of copper.
1500,	Melting point of palladium.
1775,	Melting point of platinum.

* *Op. cit.*, p. 240.

† I have always used 945° as the melting point of silver, but M. Violle makes it 954°.

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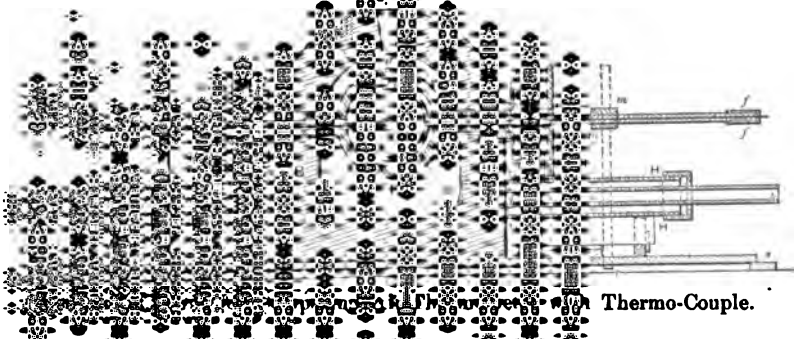

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n, 1889.

The furnace is heated by gas, introduced through the burners, G G, H H,—compressed air entering by the inner tubes, *g g*, and, *h h*. The inlets for the gas are shown at *c*, *c*. The furnaces can be heated to a high temp rature with ease; but, in order to equalize the heat, Barus employs an internal globular "muffle," E C D F. It consists of two hemispheres of fire-clay, provided with lateral tubes, which pass through the walls of the furnace. The two hemispheres are held together by the iron collars, N N, N′N′. The outer edges of these collars, P P, are flanged, and fit into the grooves of two friction rollers Q Q′, of which, R R′ are the respective axes. There are adjusting screws at V V′, *u u′*, *t t′*. The muffle is rotated by a belt-pulley screwed on to the flange, P′. The air-thermometer is shown in position, *f f k i e*, supported by the clamp, *m m*. A similar clamp, *n*, on the opposite side of the furnace, supports the thermo-couple, *k*, the wires of which are shown at *a β*. It will be observed that the thermo-junction passes directly into the re-entering tubulure of the porcelain bulb, but the wires must not touch the walls of the tubulure. The capacity of the bulb, *e*, is about 300 c.c. The muffle is turned at the rate of about 50 revolutions per minute; and this speed, which is probably needlessly high, ensures uniformity in the temperature of the furnace.

It will be evident that the arrangements briefly described above enable the indications of the air-thermometer and the thermo-junction to be compared, and full details of the experiment will be found in a monograph by Barus. It will be found* that if the results of the experiments be plotted, with the electro-motive force of the thermo-junction (in micro-volts) as abscissæ, and the temperatures indicated by the air-thermometer as ordinates, the several observations coincide very nearly with a straight line; and singularly valuable information is thus afforded as to the trustworthy character of the respective methods. The general conclusion would appear to be: that the thermo-junction, the use of which is very simple, may replace the air-thermometer, which (as arranged for accurate work) involves the employment of cumbersome apparatus and much tedious calculation—and is, in fact, about the last piece of apparatus that should be offered to engineers with a view to the measurement of temperatures in the ordinary course of work.

An air-thermometer, in a form adapted for industrial use, has, however, been devised by Professor Wiborgh, of Stockholm†, who

* *Op. cit.*, p. 226. † *Jour. Iron and Steel Inst.*, No. 2, 1888, p. 110.

measures the pressure exerted by the expansion of a known volume of air when forced into a porcelain bulb raised to the temperature which it is required to determine. Another form has recently been patented by H. L. Callendar,* who has so modified the differential air-thermometer as to enable the degrees of temperature to be read directly on a graduated tube.

It will have been evident, from the foregoing descriptions of pyrometric methods, that the form of instrument to be adopted in works will greatly depend on the nature of the operations which are conducted in them. High temperatures can be easily and accurately measured by several methods, but the condition in any particular works will determine which of the several appliances shall be employed. With a view to ascertaining which form of pyrometer is most suitable and trustworthy for adoption in works, Dr. L. Holborn and Dr. W. Wien † have recently begun an interesting series of experiments, of which we may hope to hear more shortly. E. Blass ‡ has also submitted to more or less rigorous tests the following pyrometers:

(1) The air-pyrometer of Wiborgh. (2) The thermo-electric couple of Le Chatelier. (3) The electrical-resistance pyrometer of Hartmann and Braun, in which the observations are made with the aid of a telephone. The Siemens calorimeter and pyrometric alloys were also employed.

Comparative results were made by simultaneously testing the first three pyrometers named above.

An empty 50-kilo. steel crucible, C, was placed in the interior of a crucible-furnace, Fig. 13. Inside the crucible the three pyrometers in question were inserted through tubes. There was also a fourth opening, through which portions of the combustion-gases could be withdrawn for examination.

The Braun-Hartmann instrument proved to be a most useful and accurate one, but the noise incidental to works made the indications of the telephone difficult to distinguish. Herr Blass considered that the Le Chatelier couple loses sensitiveness, and undue shaking of the galvanometer-mirror is difficult to avoid in works. He also considers that the platinum, platinum-rhodium couple changes its zero. This, I may observe, is not my experience, while, with regard

* *Pro. Roy. Society*, vol. l., 1892, p. 247.

† "Ueber die Messung hoher Temperaturen," *Zeitschrift fur Instrumentenkunde*, August, 1892, p. 257.

‡ "Berechnung von Flamentemperaturen, *Stahl und Eisen*, October, 1892, p. 893.

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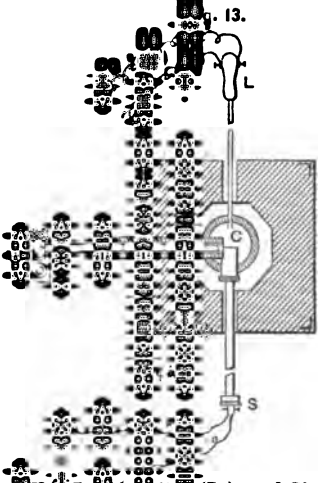

[illegible] (L.), and Siemens (S.), Pyrometers.

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[illegible] xxxv., 1893, p. 176.

the curve. The little mass need not be heated beyond redness, or the operation may involve its fusion and volatilization; but a permanent record can be obtained of minute changes in the behavior of the metal, if they are marked by the evolution or absorption of heat such as accompany the passage of a metal or alloy from a normal state to an allotropic one. The various phenomena of fusion and solidification can also be faithfully recorded when they

FIG. 14.

Automatic Record of Cooling of Copper-Tin Alloy.

occur either in the centre of a 20-ton ingot of steel or in a tiny mass of gold. On the other hand, the little pyrometer may be placed in the blast-mains of an iron or steel works and will furnish the manager with precious information and a trustworthy record (Plate II.) of the variations of temperature in the torrents of hot air which pass over the thermo-couple on the way to the seething contents of the furnace.

It remains to be seen what use the physicist and the metallurgist will make of this new weapon of research.

THE GROWTH OF AMERICAN MINING SCHOOLS AND THEIR RELATION TO THE MINING INDUSTRY.

BY SAMUEL B. CHRISTY, PROFESSOR OF MINING AND METALLURGY, UNIVERSITY OF CALIFORNIA, BERKELEY, CAL.

(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

COLUMBIA COLLEGE has the honor of founding the first well-organized School of Mines in America. The University of Michigan, however, shared with her the honor of graduating the first class, in 1867. Prof. Thomas Egleston was the pioneer in the new movement. He drew up the original plan for the Columbia School of Mines in 1863, and was in 1864 appointed its first professor.

The Massachusetts Institute of Technology turned out a class of mining students a year later, and others followed in the order of their first graduating class, as shown in Table I., condensed from the *Engineering News* of August 11, 1892.

Besides those mentioned, mining schools have been organized in the States of Arizona and Nevada, and more or less instruction is advertised in connection with other engineering schools.

It will be noticed that Columbia easily heads the list with reference to the number of graduates; the Massachusetts Institute of Technology stands second; the California University third, and then follow Lehigh, Washington University, the University of Michigan, Lafayette College, Michigan Mining School, Missouri, Colorado and the others.

The total number of graduates from these 16 schools in 26 years, has been 871, or an average of 33 per year; but as all these schools give a partial education to many who do not graduate, it is probable that from 2000 to 3000 mining students have received from them considerable training.

An interesting comparison of the rate of growth of the engineering schools has been recently instituted by the *Engineering News*, for the period between 1860 and 1892.

Table II. shows that civil engineering had the advantage in numbers from the start, and maintained the advantage until 1890, when it was surpassed by mechanical engineering. The development of the latter course may be said to date from 1880.

There are many interesting facts evident in Table II. It will

TABLE I.

*Total Number of Graduates from Mining Schools in the United States.**

Date.	SCHOOL.	No. Grads. to 1892.	Average per year.
1867	Columbia School of Mines	402	15.46
1867	University of Michigan	41	1.57
1868	Massachusetts Institute of Technology	126	5.04
1869	Washington and Lee (none since 1875)	8	.03
1871	Lehigh University	48	2.28
1871	Lafayette College	40	1.71
1874	Missouri University†	26	1.31
1874	Washington University, St. Louis	43	2.26
1877	California University	55	3.44
1878	Illinois University	6	0.40
1879	Wisconsin University	12	0.92
1882	Colorado School of Mines	26	2.60
1888	Michigan Mining School, Houghton‡	27	5.40
1890	Alabama Polytechnic	4	1.33
1891	Montana School of Mines	6	3.00
1892	Pennsylvania University	1	1.00
	Total in 26 years	871	33.05

be noticed that the curves all show inflection points in the same years. The minimum points, traced back four years, show that the year in which the minimum of graduates entered was in each case in a period of profound financial depression.

But the two most remarkable points are the enormous development of mechanical engineering since 1880, and the lack of growth of mining engineering for the same period. Thus the number of graduates from all the engineering schools was:

* It is to be understood that this list includes the graduates from the mining courses only, as the total list of graduates from most of the institutions named is many times these numbers.

† This institution, up to 1891, graduated its students on a three years' course. It now requires four years.

‡ This institution has graduated its students first, on a two, then on a three years' course. It now announces a four years' course. The rest all require four years, though some have unsuccessfully attempted to require five-year courses.

	Mining Engineering.	Mechanical Engineering.	Civil Engineering.
1880, . . .	37	41	157
1892, . . .	48	445	371
Increase, . . .	1.3 times.	10.8 times.	2.2 times.

TABLE II.

Diagram showing number of Graduates from Civil, Mechanical and Mining Engineering Schools of the United States for each year since 1880.—From *Engineering News.* Also:

Total Metallic Product U. S., 1880–1892.

Total Mineral Product U. S., 1880–1892.

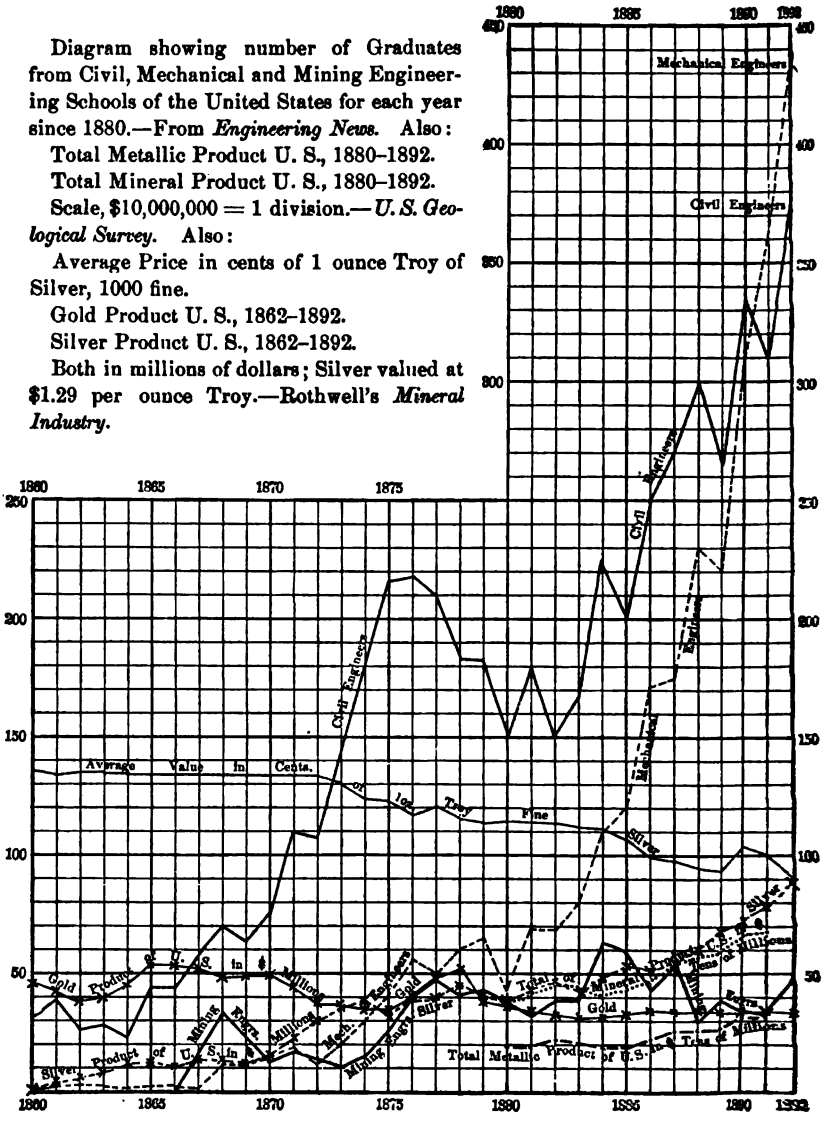
Scale, $10,000,000 = 1 division.—*U. S. Geological Survey.* Also:

Average Price in cents of 1 ounce Troy of Silver, 1000 fine.

Gold Product U. S., 1862–1892.

Silver Product U. S., 1862–1892.

Both in millions of dollars; Silver valued at $1.29 per ounce Troy.—Rothwell's *Mineral Industry.*



Three questions naturally suggest themselves: What are the causes of these great differences of growth? Are the mining schools doing their duty? Is their rate of growth proportioned to that of the mining industry?

The last question is easily answered.* According to the latest returns from Major J. W. Powell, director of the U. S. Geological Survey, the mineral product of the United States was as follows:

	1880.	1891.	Increase.
Non-metallic mineral products, . .	$173,279,135	$356,216,615	2.06 times.
Metallic product, ...	190,039,865	302,307,922	1.60 "
Estimated value of unspecified products,	6,000,000	10,000,000	1.66 "
Total, ...	369,319,000	668,524,537	1.81 "

It is remarkable that the increase (1.3 times) in the number of graduates from the mining schools, should be so close to the increase (1.81 times) in the total value of the annual mineral product of the country for the corresponding decade. In fact, no one would have ventured to predict such a close agreement beforehand.

It will be noticed that the rapid growth in mechanical engineering schools since 1880 corresponds almost exactly with the advent of electricity as a practically useful form of energy. No one can safely predict the outcome in this direction, but a reaction is not unlikely to ensue, and many young men with great expectations may meet with disappointment.

What is the Normal Relative Demand for Engineers in the United States?

This ought to be a question easily answered by a direct appeal to our census statistics. I have applied to the officers of the eleventh census, but they report the "personal statistics" to be still in an unfinished condition, as they are the last to be worked up.

In this emergency I have turned to the tenth census (up to 1880) for the actual distribution of the wage-earning occupations of the entire country. The results of this census are as follows:

Agriculture, ...	7,670,493	44.10 per cent.
Professional and personal, . .	4,074,238	23.43 "
Trade and transport, ...	1,810,256	10.41 "
Manufactures, mechanics and mining,	3,837,112	22.06 "
Total, ...	17,392,099	100.00 "

* An outline of part of this statistical inquiry was published by the writer in the *Engineering and Mining Journal*, but it has been revised and enlarged for this paper.

The total number of persons engaged in the mining industry is nowhere clearly stated in this census. It gives the total number of "engineers (civil)" as 8261, and takes no account whatever of either mining or mechanical engineers, as such. It gives, as the total number of "officials connected with manufactures and mining," 8198. To get an estimate (if anything, in excess), we assume that 4000 are in each case connected with mining, and we have, as near as may be learned from this report, the following results:

Engineers, surveyors, etc. (probably in excess),	4,000	
Other mining officials " "	4,000	
Chemists, assayers, metallurgists, etc.,	1,969	
		9,969
Stamp-mill operatives,	1,449	
Miners,	234,238	
Quarrymen,	15,169	
Iron- and steel-smelters,	55,649	
		306,505
Grand total for the United States,		316,474

This makes those engaged in mining and metallurgy, 316,474, in a population of 50,000,000; or, in a total of 17,392,099 wage-earners, those engaged in the mining industry aggregate only 1.82 per cent.; or, of the total population in 1880, the miners aggregated only 0.63 per cent.

The wage-earning population at this period was, therefore, distributed as follows:

	Per cent.
Agriculture,	44.10
Professional and personal,	23.43
Trade and transport,	10.41
Manufactures and mechanics,	20.24
Mining and metallurgy,	1.82
	100.00

Now, although some employment is given to engineers by the first two classes of wage-earners, most of it comes from the three latter classes, each of which is closely related to some one particular class of engineering work. Thus, the work of the mining engineer comes from the activity of those engaged in mining and metallurgy; that of the civil engineer chiefly from those engaged in trade and transport; that of the mechanical engineer from those engaged in manufactures and mechanics. The personnel of these industries, we have seen, were related numerically in the ratio of 1.82 : 10.41 : 20.24, or as 1 : 5.72 : 11.12. *Hence it would seem in a general way as if the*

relative field for mining, civil, and mechanical engineers in 1880 *was roughly in proportion to the numbers* 1, 6, and 11.*

Now we have found the number of graduates from the schools of mining, civil, and mechanical engineering, in 1880, were in the proportion of 1 : 4.25 : 1.11 ; and both civil and mechanical graduates, but especially the latter, were at that time much below their normal ratio.

If we examine the ratios of graduates in 1892 from the schools of mining, civil, and mechanical engineering, we find them greatly altered ; they have become 1 : 7.73 : 9.27. In short, then, unless the relative proportions of the wage-earning classes have essentially altered in the last 13 years since the census was taken, the supply of civil engineers has most nearly approached the limit of demand, and that of mechanical engineers is still somewhat below it.

It will not do to push such reasoning too far, but it must now appear evident that the apparently abnormal growth of the schools of engineering has been in reality only a readjustment to make good an abnormal deficiency in the supply of mechanical engineers.

What is the Normal Demand for Mining Engineers in the United States?

This question reaches to the root of the matter. For graduates of mining schools can hardly be expected to take a long, difficult and expensive engineering course to prepare for the manual labor of the miner, for which, indeed, such training is unnecessary. They must have in view, ultimately, the position of manager, superintendent, engineer, or chemist for some mining, milling, or smelting enterprise.

As we have seen, as nearly as can be learned from the tenth census, the number of such positions in the United States was certainly much less than 10,000, or less than 0.06 per cent. of all the wage-earners in the United States.

In order to get an idea of the demand for such men compared with the number engaged in the "learned professions," the following statistics are at least suggestive :

* Employment for civil engineers comes partly from the occasional necessities of agriculture, and partly from the constant needs of municipal work. These would increase the estimate made above for the field of civil engineers. But agriculture calls only for infrequent land surveys, while municipal work occupies the mechanical even more than the civil engineer; trade alone, as apart from transport, gives very little direct employment to civil engineers—so that on the whole I believe the above estimate is very near the truth.

TABLE III.—*Personnel of the United States Mineral Industry.*

(Compiled from the Eleventh Census "Mineral Industries.")

	Office.	Foremen.	Mechanics	Miners.	Laborers.	Boys.	TOTALS.	
Coal	2,936	a 2,285 b 2,859	8,603	 158,060	88,413 58,771	17,836 9,796	299,559	
Stone	1,086	3,590	12,017	40,386	28,814	1,481	82,374	
Gold and silver	873	a 1,585 b 1,352	8,273	 29,144	17,085 3,870	82 43	57,307	
Iron*	520	a 680 b 686	2,079	 12,432	14,531 6,479	709 111	38,227	
Copper-mining	70	a 84 b 114	741 †4,236	....	1,718 1,725	20 83	8,791	
Copper-smelting	77	193	613	.....	3,865	116	4,864	13,655
Lead-zinc mining	14	109	173	1,122	1,753	74	3,245	
Lead-smelting	249	173	354	.....	5,595	9	6,380	12,410
Zinc-smelting	95	82	457	.....	2,024	127	2,785	
Quicksilver	20	.....	.....	527	434	....	981	
Tin	?	a 11 b 6	63	 141	91 10	....	322	
Nickel	6	a 2 b 2	16	 33	85 33	10	187	
Aluminum	?	?	?	?	?	?		
Manganese	.....	.....	.....	.....	432†	.....	432	
Chromium	.....	.....	.....	.....	30†	.....	30	
Antimony	.....	a 2 b 1	....	 12	5 8	....	28	
Petroleum	173	1,854	11,084	.....	9,772	156	22,539	
Natural gas	411	874	889	.....	5,004	6	6,684	
Asphalt	2	8	2	11	113	.....	136	
Gems	.....	.....	187	.....	.....	112	299	
Phosphates	.....	110	130	.....	4,680	91	5,011	
Gypsum	.....	a 35 b 11	84	 67	460 97	7	761	
Infusorial earth	.....	3	4	.....	45	.....	52	
Corundum	.....	7	5	66	51	.....	129	
Millstones	.....	3	42	.....	51	2	98	
Whetstones	....	13	1	.....	68	9	91	
Mica	....	15	7	95	68	.....	185	
Asbestos	1	2	.....	2	7	.....	12	
Graphite	.....	6	13	14	68	.....	101	
Soapstone	.....	20	71	.....	177	12	280	
Barytes	.....	11	7	85	107	5	215	
Ocher	.....	17	14	.....	162	3	196	
Metallic paint	8	10	27	.....	151	3	199	
Fluor-spar	.....	4	8	18	69	2	101	
Sulphur	.....	2	.....	7	.....	3	12	
Pyrites	.....	7	17	75	116	22	237	
Add for omissions (est.)	142‡	.....	.....	.....	.....	.....	142‡	
	6,683	15,828	45,217	242,297	202,037	80,930	542,992	

Clergymen (10th census),*	64,698	or 0.37	pr. ct.	total	wage-earners	in the U. S.
Lawyers " "	64,137	" 0.368	"	"	"	"
Physicians and surgeons,	85,671	" 0.493	"	"	"	"
For the 3 learned professions,	214,506	" 1.231	"	"	"	"

This number, all presumably college-bred men, is more than 21 times as great as the total outside estimate of the mining officials of the United States, and almost as great as all the miners in the country put together.

In order, however, to run this matter down to the end of my material, I have compiled from the volume recently issued by the eleventh census on "Mineral Industries," the statistics for the year 1889 shown in Table III.

If we make the additions suggested in the foot-note to Table III., for the pig-iron industry, we shall have, as our estimate for 1889:

Office,	7,683	
Foremen,	17,828	
Administration,		25,511
Mechanics,		45,217
Miners,		242,297
Laborers,		202,037
Boys,		30,930
Pig-iron operatives (not steel),		53,000
Total engaged in mineral industries (1889),		598,992

It will be noted that the number of persons engaged in the industry has increased 1.88 times as compared with what it was in

* It is a curious fact that in 1880 for every saloon-keeper in the United States there were 1 clergyman, 1 lawyer, and 1½ physicians.

a. Employed "on the surface."

b. Employed "underground."

* This estimate, taken from the admirable article of ex-President John Birkinbine, is confined to *iron-ores*, and does not take into account those engaged in smelting the ores or producing iron and steel from them. In the absence of definite returns it is difficult to make an accurate estimate. If, however, we confine ourselves strictly to the production of *pig-iron* only (assuming the production of Bessemer and other *kinds* of steel production to come under the head of manufacturing, and the increase of *personnel* to be in proportion to the increase in production), we shall have in round numbers to add perhaps 56,000 men, of which perhaps 1000 ought to be included under the head of the "office," and 2000 as foremen.

† These men appear to have been entered in the report as *mechanics* or *laborers*, when they should have been entered as *miners*.

‡ Where no returns have been made for the "office," I have added as an estimate *one-half* the number returned as foremen.

1879–80, while the value of the mineral product has increased 1.78 times in the same period.

NOTE.—The absolute accuracy of these census statistics is not to be assumed. The mineral statistics are particularly difficult of attainment, and are naturally likely to be underestimated. On the other hand, in the eleventh census men were employed to collect the mineral statistics who were unusually well fitted for the task, being in most cases really noted specialists in particular lines.

Regarding gold and silver, I quote from R. P. Rothwell's able article:

"The number of gold and silver mining 'claims' or 'locations,' commonly called 'mines' in the United States, is practically beyond computation. The names of nearly 100,000 of such claims or mines were received by the census office, but upon limiting the investigation to (1) producing mines, (2) working but not producing, (3) mines temporarily stopped, but which had produced or upon which the work done had established their value, and which could properly be classed as mines, the list declined to perhaps 10,000, and upon tabulating only such mines as made returns of production or labor statistics, the list was reduced to 6004, which is still a large number compared with the other mineral-producing mines in the United States."

I call attention to these facts and to the extreme difficulty of including all engaged in this industry; for it is not unlikely that instead of 57,307 men engaged in this business, there may have been 100,000. The product was in round numbers $100,000,000, of which one-third was gold, and two-thirds silver.

Table III., which has never been in print before, is worthy of considerable study; there are many important conclusions that may be drawn from it, but they would unduly extend the present paper.

We are now in a position to make a much closer estimate of the entire number of mining and metallurgical engineers in the United States. Of the total 25,511 estimated as engaged in the administrative staff of the mineral industries, it must be plain that more than half were engaged in superintending the work of mechanics or laborers, or in clerical capacities. This would leave in round numbers about 12,000 officials connected with the actual work of mining and smelting. To those familiar with mining work it must be evident that not more than half of these would find the technical instruction of an engineering school necessary to the proper performance of their duties.

In short we may conclude that the entire mineral industry of the United States gives employment to not over 6000 *persons who may be said to require technical training as engineers.*

As corroborative of this estimate, the membership of the American Institute of Mining Engineers may be cited. The liberal basis on which membership of this society is founded insures for it, as compared with similar societies, a large proportionate membership of those interested. In 1891 it had a membership of 2092. This is one-third of the number estimated above.

The Annual Openings for Graduates of American Mining Schools.

A young man can hardly be said to be fitted for a position of technical responsibility before the age of 25 years. Let us suppose he enters the technical school at 18, graduates at 22, and serves a practical apprenticeship as workman or subordinate for 3 years; this supposition will agree fairly well with the usual practice.

At the age of 25, the average remaining life of a man is estimated at 38 years. If, now, we assume an average working life of 30 years, it must be plain that to keep up the supply of 6000 engineers, there will be required 200 new men each year.

It is evident, therefore, that the supply of graduates turned out by the mining schools in 1892, namely 48, is not so extremely out of proportion to the demand as at first sight appeared.

We must remember that most of the mining schools partly train from two to three times the number who graduate, and that the graduates from foreign mining schools also compete for places. These considerations are partly offset by the fact that all who graduate do not need or choose to follow their profession, and that some practice it abroad.

Making these offsetting allowances, it would appear that there are about four times as many openings as there are mining graduates to fill them. This is a condition of things which agrees very well with experience, and shows why there is such a steady demand for the graduates of the best mining schools.

They are reasonably sure of good and remunerative positions if, in addition to the proper training and experience, they have the peculiar natural faculties essential for success in any branch of engineering.

It must be evident to any candid mind that adverse criticism of American mining schools, founded on the small number of their graduates, is without substantial foundation.

Are Mining Schools Justified?

This question can hardly fail to suggest itself. If the mining population be so insignificant in numbers; if there be only a couple of hundred mining engineers required a year, why should we maintain expensive mining schools?

The answer, on a mere commercial basis, is not far to reach. *The miners may be insignificant in numbers, but in respect of the value pro-*

duced as a result of their labor, they are the most important element in the entire population.

Thus, in 1880 the actual money-value produced as the result of labor, per capita, was as follows:

Agricultural,	$289.00
Manufactures (gross value, less one-third for raw materials),	996.00
Mining industries (all engaged),	1167.00
Miners only,	1577.00

The statistics for the year 1889 for agriculture and manufactures are not yet at hand, but those for mining are:

Actual value produced by all engaged in the industry, per capita,	$981
Per miner only engaged,	2,900
Per administrative officer,	23,020
Per estimated engineer,	97,872

If it be true that "money talks," this showing should be a sufficient answer.

If each captain of the mining industry actually superintends and controls an average production of nearly $100,000 a year, is it not important to the nation that they should be thoroughly trained to their business? The community has a right to demand that into their training shall go all that modern science can give to make them efficient.

Surely it is not a bad investment to spend a thousand dollars a year in educating a man for 4 or 5 years who shall have the direct control of the production of $100,000 a year for 30 years! The sum total is an average of $3,000,000 as the result of the work directed by each mining engineer in the United States during his working life.

When we come to consider, not the gross output, but the net profit, these conclusions are even more strongly enforced. And when we consider the peculiar nature of mineral wealth, the value of such a policy to the nation is even more apparent.

The farmer can harvest his crop year after year; most of his increase comes from sun and air and rain; he has only to fertilize the soil now and then, and his farm remains a source of wealth from generation to generation.

But there are no fertilizers for worked-out mines. The crops the miner reaps can be harvested but once, and what he leaves behind through lack of skill is forever lost.

It is now plain why a large mining company is often justified in paying an experienced mining engineer from six to twenty-five thousand dollars a year. Such a man is often able to earn for his employers many times his salary. And it is also evident that the field for mining engineers, though limited, holds rich rewards for those who have the training, the experience, and the energy for such responsibilities. It is a field where inefficiency and weakness of body, mind, or character are signal disqualifications.

Attendance at American and European Mining Schools.

A complete comparison of this sort is difficult to make, because it is not easy to obtain the data for all of these schools at the same period, unless we select a date somewhat remote; and because in Europe it is the custom to distinguish between schools for engineers (*Bergakadamien*) and for miners (*Bergschulen*). The following data are condensed partly from Prof. R. H. Richards' admirable paper on "American Mining Schools," *Trans.*, vol. xv., pp. 814, 816, etc., and partly from other sources mentioned below.

The first striking fact which this Table shows is the small number of students of mining engineering in the famous Royal School of Mines at London. In the period from 1851 to 1890, this school has graduated in mining, metallurgy, or geology, 303 associates; of these, 27 were in geology only, which leaves for mining and metallurgy 276, or an average of 7 per year.

The other English schools might swell the list somewhat, but it is evident that the number of mining students in England is small in comparison with the English mining interests.

On the continent, where mines and mining are largely under government control, we should expect to find a very different state of affairs; but even in Germany, the birthplace of scientific mining, her four great mining schools contain only 406 students, while Austria has 117, France less than 200, and Sweden, with her famous iron industries, only 17.

Omitting Belgium, for which I have no data, it is plain that the United States had more mining students than any country in Europe except Germany, and that she had more than one-third as many students in her mining schools as Austria, England, France, Germany, and Sweden together.

It must be evident that the attendance at mining schools, the world over, is extremely small compared with that of the schools of law, medicine, and theology. Thus the attendance at the Berlin

Mining School (*Bergakadamie*) for 1887 was 104, while at the Berlin Institute of Technology (*Technische Hochschule*) it was over 1100, and at the Berlin University over 5000.

TABLE IV.—*Attendance at Mining Schools for* 1887.

AMERICAN.		EUROPEAN.		
Columbia	87	*England*—Royal School of Mines		60*
Lehigh	68	*Saxony*—Freiberg		163
Massachusetts Inst. Tech.	30	*Prussia*—Aachen	43	
California	23	Berlin	104†	243
Pennsylvania	17	Clausthal	96†	
Ohio	14	*Austria*—Leoben	29‡	
Lafayette	12	Klagenfurt	8	
Michigan	8	Mährisch-Ostrau	23	117
Washington	7	Dux	17	
Illinois	3	Prizbram	40	
Wisconsin	3	*Sweden*—Stockholm		17
Total	272	*France*—École des Mines de Paris	111	191
		École des Mines, St. Etienne	80	
		Belgium—Liège		—
		Total		791

But it would be a great mistake to conclude from their small numbers that these schools are unimportant. In collecting materials for this paper I happened on a list of the 76 Americans who studied at Freiberg between 1819 and 1865. The names of 25 of these have become familiar as household words to all members of the mining profession in America. They have become leaders in nearly every branch of mining and metallurgical enterprise. The industries of coal and iron and steel, of copper and lead, and gold and silver, are all debtors to these old-time students of Freiberg.

The mining schools of Paris, Berlin and London have educated

* This estimate for students in the Royal School of Mines proper, for 1887, is made by an associate of this school. There were several other schools in England giving some instruction in mining, but this seems to have been at this time the only one with a regular course for mining students.

† *Preussische Zeitschrift für Berg-Hütten-und Salinenwesen*, Bd. 38, S. 378 B.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, 1889, Bd. 37, S. 224.

many brilliant American engineers, and if the influence of these mining schools could be blotted out from American mining practice, it is safe to say that the record of which we are so proud to-day, would never have been made.

Difficulties Peculiar to the American Mining Schools.

In Germany and Austria the mines are largely under government control, and are worked, not so much for immediate results, as to get the greatest ultimate yield. In America they are exclusively under private control.

The American system has many distinct advantages, particularly in a new country. Routine and precedent are thrust aside, and energy and originality have full sweep. But it must be admitted that there are serious drawbacks to this system. Not infrequently mines are owned and controlled by persons without the slightest technical knowledge, and often by those interested more in the speculative than the productive value of the property; and in such cases a thoroughly trained mining engineer is not a desirable superintendent. Any man who will work the mine for the market will do better.

This policy, which often enriches the speculator in a fabulous manner, leads the public to think that a long course of training is unnecessary to the mining engineer, because the most successful operators in this kind of "mining" have been without it. The failures which overtake most men of this class are seldom noticed, as in a lottery one success hides a hundred failures.

As a single comparison: the Idria mine in Austria was discovered almost in the same year that Columbus discovered America. It has been in almost continuous operation ever since. Every resource known to science has been tried, to ensure the greatest ultimate yield. For over 400 years it has given employment to generation after generation of miners, and has yielded a small but steady income on the outlay.

Compare with this record the history of the Comstock lode. If the Idria mine had been in America it would have been "worked out" in 25 years, and have produced perhaps two or three millionaires. Which system is in the long run better for a country, it is not hard to decide.

If a government is ever justified in controlling the business affairs of its people, surely the mineral wealth of a country, and the conditions under which it should be removed, are the ones which most need regulation and control.

Nevertheless, in the present condition of our civil service, such a change would only add to the difficulties and dangers of our government, and may be dismissed as impracticable.

But the bearing of the above facts on the engineering schools is evident. On the continent of Europe the only road to success lies through the mining school; in America there are many "short cuts," and the man who takes them learns his mistake too late to profit by it himself, and is often too proud to admit it by warning others.

Again, the work of the mining engineer always involves more unknown and indeterminate quantities than that in any other branch of engineering. Moreover, it is more remote from business- and money-centers; it seldom receives the same intelligent and appreciative criticism that awaits the work of the civil and mechanical engineer. Their work is always in the eye of the public. His is hundreds of feet below daylight, and hundreds of miles from the public centers. In the best case, mine owners are forced to estimate the capacity of their engineer or superintendent, not from the difficulties he overcomes, but from the dividends he produces.

Nevertheless, as the more easily worked mines are exhausted, it is certain that the value of technical training will in the future of American mining practice become more and more recognized. No one can deny that American mining is carried on with an energy and force which is the admiration of the world. But I believe none would more readily admit the need for better scientific and technical training, than those to whom we are most indebted for the advances we have made; for none are better aware of the enormous waste that results when ignorance and incompetence are at the head of affairs.

But mining schools labor under another difficulty, that other engineering schools do not have to meet. The miners, their peculiar constituency, are scattered over the most remote and inaccessible quarters of the globe. Other schools may draw their best materials from the densely populated centers in which they are placed. But much of the best material for the mining schools is obtained from among the sons of the miners themselves. Now the situation is this: these young men, except in rare instances, are utterly unable to acquire more than the merest elements of a general education. The requirements for entrance to an engineering school are in such cases as absolutely beyond their reach as if they were the inhabitants of another planet.

Some attempts have been made to move the schools to the mining

centers. More students may be at first secured from among the miners, but it is necessary for the schools to give them elementary instruction for several years before they can properly be called engineering students. There would also need to be an engineering school for each mining center, which is impossible. This solution of the difficulty is therefore more apparent than real.

Most schools attempt a partial solution of the problem by admitting men from the mining regions as "special students" to such classes as they are fitted to enter. Most of them confine themselves to such studies as can be pursued without mathematics, so that few of them are finally able to graduate, but these few who take the whole course attain success of a high order.

To reach and help this class of material is, I take it, the real problem of the mining schools.

On the continent of Europe, where the mines are largely under government control, this lack of provision for the lower mining education does not exist. Thus, in Prussia in 1889 there were at the mines 10 *Bergschulen*, with 408 students, and 29 *Berg-Vorschulen*, with 482 students, for foremen and workmen respectively. A similar practice holds in Austria and France.

Under American conditions such a solution of the difficulty seems impossible. Nevertheless, a remedy may not be entirely out of reach.

An interesting enterprise has been recently attempted by the *Colliery Engineer*, of Scranton, Pa. It is called the "Correspondence School of Mines." This school claims to have 1700 pupils. It claims to teach by the method of correspondence for its "Full Scholarship" of $50, "*to any one who knows how to read and write*," the following subjects: "1. Arithmetic, 2. Ventilation, 3. Geology, 4. Search for Coal and other Minerals, 5. Modes of Working, 6. Surveying and Mapping, 7. Mechanics, 8. Mechanical Drawing, 9. Ambulance, 10. Mine Legislation, 11. Mine Accounts, 12. Blowpiping, 13. Mineralogy, 14. Assaying, 15. Economic Geology, 16. Prospecting."—*Circular* of 1893, pp. 16, 22. "The Full Scholarship will take a quick student, *who can only devote his time after working hours to study*, 24 *months. If the student knows nothing of Arithmetic when he commences, it will take longer.*"—*Ibid.*, p. 46. "*Algebra is not used*," p. 15. [The italics are mine.]

When it is considered that the usual mining school occupies its students an equivalent of 10 hours a day, 9 months in the year for 4 years, and that they are already familiar with arithmetic, algebra, geometry, and much more to begin with, it will, I think, be seri-

ously doubted whether (with the working miner) all this ambitious programme can be fulfilled to the letter. It must be evident that such an undertaking cannot train mining engineers, and, as I understand, it makes no such pretensions.

Nevertheless, it seems to me that the method here indicated is almost the only one which can reach small outlying groups of miners. The fact that 1700 persons, many of them evidently working miners, have enrolled themselves, shows that a need is felt among them for some instruction.

If now, instead of offering "diplomas" for the course advertized, it were modified so as to correspond more to the entrance-requirements of our best mining schools; and it could be shown that such a course would enable a young man at a mine to prepare himself for the full course in the best mining schools, a most important advance would be made.

It is evident that there is no justification for a school for miners unless it can teach them something they need to know, that they cannot learn at the mine. Besides the ordinary English branches, such a course might include arithmetic, bookkeeping, geometry, algebra, trigonometry, elements of physics, chemistry and mineralogy, the two latter taught largely by means of the blowpipe. The problems and illustrations might be drawn almost entirely from mining practice, and the course would be equally useful to a miner, whether he afterwards wished to attend a school of mining engineering or not.

If some such plan as this could be carried into effect, it would help to bridge the gap between the miner and the mining school, and would make available for mining engineers some of the best material in the country.

The Future of American Mining Schools.

Since the memorable address of the lamented Holley, in 1876, on the "Inadequate Union of Engineering Science and Art," the conditions have changed in all our engineering schools, and in none more than in those for mining engineers.

These changes have resulted mainly from the initiative taken by the Columbia School of Mines and the Massachusetts Institute of Technology.

Alive to the difficulties of the situation, Professor Robert H. Richards and his colleagues at the Institute devised, organized, equipped and first perfected the so-called "Mining Laboratory."

This is in reality a working laboratory in the college, where problems in ore-dressing and metallurgy may be worked out by the student, as Prof. Roberts-Austen well says, "Very nearly on a scale of 12 inches to the foot." Its utility is everywhere acknowledged, and it may be said to be an essential part of the typical American Mining School.

The contribution of the Columbia School of Mines is largely due to the foresight and energy of Prof. Henry S. Munroe, who first organized and made effective, as a means of systematic instruction, the "Summer School of Practical Mining," from what had hitherto been a mere summer jaunt without definite plan or purpose.

It seems to me that these two independent solutions of the difficulty are equally indispensable. The one enables theory and practice to blend during the school year; the other forces the student during his vacations to realize the working conditions he must meet after he graduates, and enables him to adjust himself to them before he makes the final plunge. Taken together, these methods make the continuous blending of engineering science and art for which Holley made his eloquent appeal.

These new methods have had a most admirable effect, not only on the student, but upon the professor and upon the school. They keep all in touch with the working miner and his needs.

In the Summer School lies the best method of bridging over the gap existing between the man practiced in the school and the man schooled in practice. Between them there is always a lack of sympathy, and, on the part of the latter, often a latent distrust, if not active jealousy. But they must work together in harmony to produce results. There is no way to understand the miner like that which comes from doing his work and sweating under his burdens, and the engineer who expects too little or too much of his subordinates seldom accomplishes anything.

I believe the Summer School is capable of much greater development than it has yet received. Utilized to the full, it gives the mining student, at annual intervals, four periods of nearly three months each, wherein he may attain a wide range of personal experience in surveying, field geology, mining and metallurgy, thus fitting him at once for a position of *subordinate responsibility* on graduation.

Whatever may be the future of American mining schools, I believe the Mining Laboratory and the Summer School of Practical Mining will prove enduring and characteristic features.

A peculiarity of the American mining schools, as well as of

American universities seem to be an over ambition to provide for the higher branches of education, together with a lack of adequate provision for the lower preparatory branches. Now, if there be a demand for 200 mining engineers a year, there must be a need for double the number of mine foremen. To graduate 200 engineers a year would necessitate perhaps 1000 students. This number could be taught by 10, or even better by half-a-dozen, schools. Schools of mining engineering are expensive; two million dollars is a minimum endowment to make such an engineering school really effective, and three would be better; while many elementary schools of great usefulness to miners could be established for much less.*

There are now perhaps twenty more-or-less endowed mining schools in America. It would be a distinct gain if the field could be sub-divided. If all having less than two million dollars endowment available for the actual needs of the mining school were to confine themselves to elementary instruction preparatory to the higher work of the other schools, two great advances would be made.

We should probably have perhaps half-a-dozen schools for mining engineers and twice that number for mine foremen. The mining schools of the first order might contain, together, a thousand students, and those of the second order perhaps four thousand.

The instruction of the latter might be partly by correspondence and partly personal, so that the actual needs of the miner could be met. The object of such schools should be to fit the miner for those duties as foremen, which require some scientific training. It should also fit for the engineering schools the few among them who display signs of distinguished ability.

The six schools of mining engineering thus relieved of elementary work, and with bodies of students sufficiently great in numbers to secure that *esprit de corps* so necessary to any body of professional

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* Two million dollars may seem a large sum, but it is easy to demonstrate that an adequate equipment and teaching staff can not be provided for less. In most cases, under American conditions, such endowments are justified only when the mining school is a part of a large and strong institution. A single National School of Mines might at first sight seem justified as a measure of economy. But after a school reaches a certain size, duplication of plant and teaching force is in any case necessary, and the single school would lack not only the power of adapting itself to local needs, possessed by half a dozen properly distributed schools, but also the advantages secured from a healthy rivalry. The latter is a factor in sound growth not to be ignored.

men, would be able to devote themselves to engineering work of a high order.

In each of these schools the same course of scientific training and the same firm grasp of principles which govern engineering practice are necessary. But it is impossible for any one of them to cover in detail the whole range of engineering practice, and it is a mistake even to attempt it.

With a firm grasp of principles, the student needs to acquire that art of all arts to the engineer, the faculty of working up his details as he needs them. Such a man succeeds where cyclopædic erudition fails. Important in the training of all engineers, this faculty is vital in all mining practice. It is best acquired, not by attempting a superficial knowledge of the details of the whole art, but by actually mastering, from the bottom up, the details of a few well-chosen typical branches.

Another great saving of energy would be effected if the schools were to select for this detailed study mainly, though not always exclusively, those branches locally most important and readily studied in detail. Particularly for summer-school and laboratory-work, subjects could be selected by each school from one or more of the heads named in some such list as the following:

(1) Mining and dressing of coal and iron.
(2) Metallurgy of iron and steel.
(3) Mining and smelting of cupriferous ores.
(4) Mining and smelting of silver-lead ores.
(5) Mining and smelting of zinc-lead ores.
(6) Mining and milling of gold- and silver-ores.
(7) Lixivation of gold-, silver-, and copper-ores.
(8) Mining and metallurgy of quicksilver and the minor metals.
(9) Quarry-work.
(10) Hydraulic mining.*

The whole mining field of the country could be thus divided up among a half dozen strong mining schools, which, taken together, would better serve the needs of the community than any National School of Mines that could be founded.

Suppose that each of these schools, after a sound course in the physical sciences and the underlying principles of the art, were to concentrate the energies of its advanced students on the detailed

* In making out the above list I have chosen to group together things industrially related, for they are most readily studied at the same place. The first two subjects include over half the mineral workers in the United States.

study, at first hand, of such technical questions of local importance as were within their time and power. Fewer subjects would be covered, but more engineers would be trained. Wisely administered, this policy would not lead to narrowness. For mining engineering, is above all things, the application of science to local conditions; and the student who has once clearly set before himself an end to be reached, has met the local conditions face to face, and has mastered them, is better equipped to triumph even in a widely different field, than he who has been painfully armed at every point with precedents. Precedent may make the lawyer and the scholar, but it can not make the man of science, and least of all the engineer.

The right to confer the degree of Mining Engineer should be confined to mining schools of the first order. The degree should be given only to those students who have not only successfully completed the full course of study, but who have had at least three years of practical experience in a position of subordinate responsibility. In short, it should be granted only to those who actually are engineers, and not, as now in many cases, to those who are only prepared to become such at the expense of their employer. The degree should be open on equal terms to self-educated men.

The right to confer the certificate of Mine-Foreman should be given to the mining schools of the second order. The certificates should be given only to those who had not only passed the necessary examinations, but had had at least five, or better ten, years of experience in the actual work of the miner.

Under these conditions there could be no question as to the competence of the holders of such certificates and degrees. Such papers would possess a real value.

It is unlikely that our national government will ever assume the ownership of its mines, although our States still retain the right to prescribe, by legislation, the conditions of their safe working, as they do the sale and use of drugs and medicines. Some of our coal-mining States have already required certificates of competency from mine foremen, and the systems in vogue, though not always above criticism, have resulted in the saving of many lives. State requirements, fixing a certain standard of theoretical training and actual experience for all who practice mining engineering, would effect a large saving of lives, of capital, and of mineral wealth.

Such laws would prevent men without training from receiving positions of responsibility, and at the same time would leave great freedom of choice to the mine owner.

But it is so foreign to our national tendencies that it is improbable that our mining schools will ever receive the backing that comes from the government control and ownership of mines. Nevertheless, there is such an inherent force in earnest convictions that even without it much may be accomplished by the co-operation of those who think and feel alike. The brilliant success of the American Institute of Mining Engineers is an example of what may be accomplished by private action. No law holds it together, yet few governments have done more to elevate the profession than this Society.

If half-a-dozen of the most active of our mining schools were to take common ground on some of these questions, and were to receive the hearty backing of the leading mining engineers and mine owners of the country, much could be done to establish, in fact, the bond of union between the mine and the mining school which in America does not exist in law.

As I have called special attention to the comparatively small number engaged in the mining industry, I cannot close this paper without one word more as to the importance of the miner to the nation. Less than two per cent. of all the wage earners in the country are engaged in the mineral industry, but fully eighty per cent. of all of them are directly dependent for their livelihood on either the production or the consumption of the miner.

Agriculture and mining are the only fundamental arts. Without agriculture, existence would be precarious; without mining, civilization impossible. Wood might indeed replace coal; but without iron and steel, without copper and lead, the locomotive, the ocean liner, the deep-sea cable and the overland wire, the press, the loom, the ploughshare and the pruning hook would melt away. Without gold and silver, commerce would stagnate, one by one our boasted arts and sciences would disappear, and the darkness of the stone age would overtake us. It is no exaggeration to claim that civilization rests upon a metallic basis.

The little army of miners is no longer insignificant. Who can withhold from its members an involuntary tribute of respect, when we view the smallness of their number, and the importance of their work; when we reflect upon the uncertainties, the hardships, the dangers which surround them; explorers of another world; sailors, who drive through seas of solid rock; soldiers, whose daily task is a battle with difficulties, danger, and sudden death—the advance guard of civilization, the salt of the earth!

THE HEAT-TREATMENT OF STEEL.

BY HENRY M. HOWE, A.M., S.B., BOSTON, MASS.

(Chicago Meeting, being part of the International Engineering Congress, August, 1893.)

I. INTRODUCTION.

This paper may be regarded as a report of progress of an investigation into the influence of prior exposure to different high temperatures, under different conditions, on the properties of steel after it has been cooled completely. The following are the chief divisions:

II.—Experiments on toughening manganese-steel by sudden cooling.

III.—A study of the critical points of common or carbon-steel, chiefly by examining the spontaneous retardations which occur in heating and cooling it, and by examining the ductility of pieces of steel which have been cooled suddenly from different temperatures by quenching them in water or brine.

IV.—A brief note on Osmond's theory.

V.—A study of the critical points by examining the ductility of pieces of steel which have been cooled slowly from different temperatures at, above, and below them.

VI.—A description of the furnace used, with notes on thermo-electric pyrometry.

It remains to throw further light on the questions studied by ascertaining the condition of the carbon and the hardness proper, and by studying the microstructure and the fracture of the many pieces treated. I hope to present later the results of experiments in some of these directions.

With few exceptions, the experiments have been performed in my private laboratory. I tender sincere thanks to my assistant, Mr. William Haskins, S.B., on whom most of the labor has fallen, for his zealous and intelligent co-operation; to the Sterling Steel Co. for their extra hard steel, Series 17; and to Mr. Joseph Hartshorne and the Pottstown Iron Co. for their soft basic steel. Series 8, 9, 10, and 18 were supplied by Messrs. Spaulding, Jennings & Co., of the West Bergen Steel Works; to them also my thanks are due.

The temperature of the pieces treated has been very carefully

regulated, and has been measured with accuracy by means of the thermo-electric couple devised by Le Chatelier, using the dead-beat galvanometer of Deprez and d'Arsonval. In cases where extreme accuracy is especially desirable, I believe that the error in measurement rarely exceeds 3° C. I here refer not to the error in the absolute temperature, but to the error in the difference between temperatures, the effects of exposure to which are to be compared closely, *i.e.*, the relative error.

As the present study aimed chiefly at a rough survey or reconnaissance of the field, extreme accuracy has, however, at times been purposely sacrificed to expedition. First let us learn the general features of our laws, and later study with accuracy the important ones which we have thus rapidly discovered.

Nearly all the heatings have been carried on in a furnace which I designed for work of this kind, and which I call a "tube-muffle."

II. Experiments on Toughening Manganese-Steel by Sudden Cooling.

(2) The remarkable toughening which manganese-steel undergoes when cooled suddenly is now generally known under the name of "water-toughening." Some attempts to learn the conditions under which this toughening occurs are recorded in Tables 5 and 6. The former treats chiefly of variations in the rate of cooling as affecting unforged cast manganese-steel; the latter treats of variations in the temperature at which cooling begins, and of the persistence of the toughness due to quick cooling, in case of forged manganese-steel.

I adopt the bending test because it gives comparable results so very quickly and at such slight cost. I bend the treated bars between dies under a hand press till rupture occurs, or till they are bent double.

(3) *Variations in the Rate of Cooling and in the Quenching Temperature.*—In their natural state, direct from the mould, after grinding roughly with emery, cast bars $\frac{5}{8}$-inch square and $6\frac{3}{4}$ inches long bent only 6° on rupture; yet, after very fast cooling, they bent 212° without breaking through.

It was to be inferred from Hadfield's experiments that, as we raise the quenching-temperature and as we increase the rapidity of cooling, or, in short, as the cooling becomes more violent, so does the toughness of the quenched metal increase. This we may call the direct effect of the violence of cooling. We may discriminate sharply

between this direct toughening effect and the effect of residual stress which rapid cooling should set up, and which we should expect would be very marked in a material which conducts heat so slowly, because this stress is due to difference in the rates at which different layers cool and hence contract. Such residual stress should in itself tend to make the steel brittle. Suddenness of cooling then should have two opposite effects on toughness; directly it increases toughness; indirectly, through causing stress, it should lessen toughness.

We might fear that when the violence of cooling reached some determinate limit, the enbrittling stress-born effect of any further increase of violence might outweigh its direct toughening effect. This would be especially dreaded in case of pieces most liable to receive stress on rapid cooling, *e.g.*, thick pieces and those of suddenly-varying sections. Experience shows that it is possible, under favoring conditions, to crack such pieces by violent quenching. I infer unhesitatingly that we are even more liable to induce injurious stress, outweighing the direct toughening effect, than thus to break up continuity.

In the present experiments, however, made on thin pieces of regular constant section, every increase of violence caused a further increase of toughness; in other words, no limit was found beyond which further increasing the violence of cooling failed to increase toughness further.

The influence of the rapidity of cooling is shown in (3 a) by comparing bars quenched from the same temperature in media varying in conductivity; and, the medium being constant, by comparing in (3 c) to (3 g) bars quenched intermittently, or after partial cooling in the air, with those held in the cooling bath till cold.

(3 *a*) *Influence of Different Quenching-Media.*—Taking these media in the order of conductivity, iced brine first, then cold water, boiling water, oil, and molten lead, we find in Tables 1 and 5 that the ductility of the quenched metal, as measured by the degree through which it bends, stands in the same order, viz.: 212°, 170° and 110° (flawed piece), 125°, 106°, 100°, for bars A^{21}, E, F, G, A^{22}, and A^{20} respectively, which were quenched from about the same temperature. So with bars 4, 8 and 15, which were quenched from a common temperature. The first two, quenched in cold water, bent 78° and 80°, respectively; the last, quenched in boiling water, bent only 56°. Bars 14 and 16, though quenched from this same temperature in iced water, bent only 48° and 58° respectively; but this may be explained by their breaking at flaws.

TABLE 1.—*Influence of Quenching-Medium on Ductility of Manganese-Steel.* (Cast bars, ½-inch square.)

Bar No.	Quenched from.	Quenched in.	Degree bent.
A^{21}	1050°C. +	Iced brine	212°
E	"	Cold water	170
G	"	Boiling water	125
A^{22}	"	Oil, intermit'ntly.	106
A^{20}	"	Molten lead	100
4 and 8	952° C.	Cold water	78° and 80°
15	"	Boiling water	56

Neither here nor in Hadfield's tests* does iced water give better results than water at the common temperature.

(3*b*) *It Is Best to Quench from a Very High Temperature.*—By comparing bars 1, 4, and 8, which broke at from 78° to 83° after quenching from 952° and 992° C., with those quenched in water from above 1050° C., which (when not injured by flaws) bent at least 135°, and, in one case, 210°, we see how important a high quenching-temperature is. Even those quenched intermittently from 1050° C. +, bent better than those quenched uninterruptedly from 992° and 952°. Group IV. of Table 5 shows us how rapidly the benefit caused by quenching decreases with the quenching temperature. Taken in connection with bar A^{20}, which bent 100° after quenching in molten lead, they indicate that the toughening is due chiefly to a rapid passage through the upper ranges of temperature, say from a moderate yellow heat to dull redness; and that rapidity of the further cooling from dull redness down, while beneficial, is much less important. It is certainly very striking that, though metal quenched from 952° C. will bend 80°, if we allow it to cool to 743° before quenching, it will bend only 26°; and if we further defer quenching till it cools from 952° to 592° it will bend but 18°, or only 12° more than an untoughened casting.

Table 2 condenses some results which bear on this subject.

(3*c*) *Slightly Deferring the Immersion is Practically Harmless.*—This is shown by bars H and J, group III., Table 5, which were held 15 seconds and 30 seconds, respectively, in the air before quenching. In 30 seconds the exterior of the bar had cooled from a low

* Excerpt *Proc. Inst. Civ. Eng.*, xciii., 1887–8, part iii., p. 46.

TABLE 2.—*Influence of Quenching-Temperature.*

Quenching temperature, C			1050°C. +	Light Red.	952° C.	808° C.	664° C.
			DEGREES BENT.				
Cast bars free from flaws.	Quenched in cold water		128° *a* 210°	.....	78° *a* 80°	.....	.....
	"	" boiling "	125°	.....	56°	.....	.....
Rolled bars	"	" cold "	Degrees bent...	180°+	180° +	180°+	147°
			Maximum aperture after hammering close till the bar broke...	0.25″	0.44″	0.53″	.....

"*Maximum Aperture*" *Defined.*—Many bars can, without breaking, be bent till their ends touch, but yet break when we press them closer together and before they are completely flattened down. For comparing such bars with each other, the angle through which they have bent is no just measure of their relative ductility. Another measure suggests itself. The more ductile the bar, the closer can its two halves be pressed together before it breaks, and the smaller will be the distance between those halves when rupture occurs. I call this distance the "maximum aperture." Roughly speaking, the ductility is inversely as the maximum aperture.

white heat to a moderate red heat. The interior of the bar, doubtless, had lost very little heat. These two bars bent 180° and 205° respectively before cracking, and 200° and 210° respectively, before breaking. This result is what we should anticipate. The material conducts heat so slowly that its interior is not considerably cooled during moderate exposure to cold air. These bars actually bent farther than those (E and F) which were quenched immediately and uninterruptedly; but the latter were injured by flaws.

(3*d*) *A Slight Retardation of Cooling Does but Slight Harm.*—This is exemplified by bar A^{25}, which, instead of being held in water until it was cold, was simply immersed for two seconds, held in the air for two seconds, then re-immersed for two seconds, and so on until it was cold. This procedure retarded the cooling very markedly, yet the bar bent 165° before cracking, and 193° before breaking apart.

(3*e*) *A Great Retardation of Cooling Can be Tolerated.*—Carrying this simple idea farther, bars A^{23} and A^{24} give like results. They were held alternately in water and in air for 3-second periods in each medium in case of A^{24}, and for 5-second intervals in case of A^{23}. They bent 128° and 135° respectively. Bar A^{22} was in like

manner dipped intermittently into oil, held in the air, re-immersed, and so on. It bent 106° before breaking. Bar G was held in boiling water till cool; it then bent 125°.

The toughness given by this greatly retarded cooling is certainly much less than that given by uninterrupted cooling in water; nevertheless I believe that it is more than sufficient for most purposes.

(3*f*) *Rapidity of Cooling not Imperative Below Dull Redness.*—Bar A^{20} was immersed in molten lead, withdrawn, and re-immersed repeatedly, until its exterior had sunk to *about* dull redness. The temperature was not clearly noted, but it must have been considerably above the melting point of lead. The bar was then allowed to cool in the air completely. It bent 70° before cracking, and 100° before breaking. It is thought that this toughness is greater than will often be needed.

(3*g*) *Applications.*—The application of these results to the case of thick castings, and of those of irregular cross-section, is obvious. Though none of the bars experimented on were noticed to crack, even on the most sudden cooling, yet such a result is to be feared in case of very thick castings. An obvious precaution would be to cool relatively slowly, as for instance in a jet of air or a spray of steam, or of mixed air and water, or by intermittent quenching. We may infer, also, that no special precautions for getting the water inconveniently cool are needed, or for extreme and precipitate haste in conveying the metal to the quenching tank, which, moreover, may be located in any convenient place, without reference to extreme rapidity of transfer from the furnaces to it.

In considering these results we must not forget that, as is shown in a special column of Table 5, some of the castings broke at flaws.

(4) *Castings Should be Heated Slowly.*—Because manganese-steel conducts heat extremely slowly, if it be heated suddenly its outside will become very hot and will expand greatly while its inside is still cool and has expanded but slightly. Though this unequal expansion may do no direct harm to such a tough substance as forged and toughened manganese steel, yet it may crack the relatively brittle untreated castings; and even if it does not it may defeat sudden cooling. This, to be effective, must start from a very high temperature. If either castings or forgings of manganese-steel be heated quickly, at the time when their outside is as hot as it can safely be, their inside may yet be so cool as to receive no important benefit from the sudden cooling.

This is illustrated by group VI. of Table 5. Bars B 1, B 2, C and D, heated to whiteness very rapidly and quenched in cold water, bent in four cases less than 46°. The fifth bar indeed bent 70°, after being held for 30 seconds in the air before quenching. This suggests that during the 30 seconds that the bar was held in the air, although the outside became visibly much cooler, and therefore should be less benefited by the sudden cooling, nevertheless, this injury was outweighed by the fact that the heat from the outside soaked into the interior of the bar, raised its temperature, and thus increased the benefit of quenching. But this bar may have been heated less quickly than the others.

Even this rapid heating was not without benefit. A bend of from 29° to 45° is certainly very much better than the bend of only 6° which the untreated metal gave.

If rapid heating thus lessens the benefit of quenching such thin pieces, how much more must it be avoided in case of thick pieces, whose interior can be but slightly warmed by the time that the outside, if heated quickly, is as hot as it can safely be.

(5) *Influence of Repetition of Quenching.*—The results condensed in Table 3 from Tables 5 and 6 do not show that repeating the heating and quenching increases the toughness of the material, though final conclusions cannot safely be drawn from such scanty data. Their showing is what we should expect; for the effects of previous quenching seem to be obliterated by a subsequent slow cooling, and those of slow cooling seem to be effaced by later quenching, as I shall now try to show. Hence we should expect that the reheating for the purpose of requenching would in itself efface the benefit of the previous quenching. The injury done by slow cooling, and illustrated by group IV. of Table 5, and to a smaller extent by bar 23 of Table 6, has previously been well established. Bar A of Table 5 further shows that this injury is readily cured, simply by reheating and quenching. It was first cooled slowly from whiteness, which must have made it extremely brittle. It was then reheated to a little above 1050° C. and quenched in water; it was then as tough as any of the other bars tested, and did not break quite across when bent 208°.

(6) *Quenching Effaces the Injury done by Previous Slow Cooling.*—Rolled bar 10, Table 6, after cooling slowly was reheated to 952° and quenched in cold water, when it was bent double, and did not break till it was hammered together so closely that the maximum aperture between its sides was 0.37 inches. Thus it was actually

TABLE 3.—*Influence of Repetition of Quenching.*

Material.	Quenching temperature.		Number of Times Heated and Quenched.		
	C.	F.	Once.	Twice.	Thrice.
			DEGREES BENT.		
Cast bars.....	952°	1746°	78° and 80°	90°	82°
Rolled bars.	Light red.....		180° + 0.25″ = maximum aperture.*		
	Low yellow...		.....*180° + ...Maximum aperture = 0.22″		

* See note to Table 2.

slightly tougher than bar 1 which had been quenched from the same temperature, 952° C., without previous slow cooling.

(7) *Reheating Destroys the Benefit of Previous Quenching.*—Table 4, condensed from Tables 5 and 6, shows this. We note that in each

TABLE 4.

Reheating Effaces the Effect of Previous Quenching.

Seven Bars were First Quenched from 952° C., 1746° F.

Bar 1, not Treated Further, Bent Double and was Hammered Down Nearly Close Before Rupture.

Bars 2, 3 and 4 Quenched After Reheating to....	808° C.	664° C.	542° C.
Bent.....	183°	110°	176°
Bars 5, 6 and 7, Cooled Slowly After Reheating to these Same Temperatures.....	808°	664°	549°
Bent.....	144°	89°	164°

case the quenched bar bent farther than that which was cooled slowly.

The bar which was cooled slowly from 664° C. seems to present an anomalous result. If we except it, the following inferences suggest themselves, but they must be taken cautiously because the cases are so few. The higher we reheat, the more we efface the toughening caused by the previous quenching, and hence the more brittle the metal, if we now cool it slowly. If, however, we again quench it, this second quenching will to a certain extent remove the injury caused by reheating, and the more so the higher the temperature

TABLE 5.—*Influence of Heat-Treatment on Cast Manganese-Steel bars $\frac{5}{8}$-inch square and $6\frac{3}{4}$ inches long.*

SERIES 7.

Group.	Bar No.	Laboratory page.	Treatment. Heated to °C.	Heated to °F.	Further Treatment.	Quenched in	Bending Test. Cracked at	Broke at	Broke at flaw or not
I. Not treated.	.....	.....	.....	.....	.....	.....	.....	6°	
II. Heated and quenched in water.	1	28	992°	1818°	.....	Cold water.	.....	83°	
	4	90	952°	1746°	.....	" "	.....	78°	
	8	94	952°	1746°	.....	" "	.....	80°	
	E	115	1050° +	1922° +	.....	" "	148°	170°	Yes.
	F	115	1050° +	1922° +	.....	" "	75°	110°	"
III. Heated, then cooled at different rates.	15	101	952°	1746°	.....	Boiling "	.....	56°	
	14	100	952°	1746°	.....	Iced "	.....	58°	"
	16	102	952°	1746°	.....	" "	.....	40°	"
	A^{25}	137	1050° +	1922° +	Quenched intermittently with intervals of 2 sec.	Cold "	165°	193°	
	A^{24}	137	1050° +	1922° +	Quenched intermittently with intervals of 3 "	" "	102°	128°	
	A^{23}	137	1050° +	1922° +	Quenched intermittently with intervals of 5 "	" "	105°	135°	
	H	115	1050° +	1922° +	Before quenching cooled in the air for 15 sec.	" "	180°	200°	
	I	115	1050° +	1922° +	Before quenching cooled in the air for 30 "	" "	143°	163°	"
	J	115	1050° +	1922° +	Before quenching cooled in the air for 30 "	" "	205°	210°	
	A^{20}	137	1050° +	1922° +	.....	Molten lead.	70°	100°	
	A^{22}	137	1050° +	1922° +	Qu'nch'd int'rmit'ly.	Oil.	84°	106°	
	G	115	1050° +	1922° +	Quenched.	Boiling water	107°	125°	
	A^{21}	137	1050° +	1922° +	Quenched.	Iced brine.	202°	212°	
IV. Heated, then quenched after partial cooling.	3	64	988°	1810°	Slowly cooled in tube-muffle to 844° C	Cold water.	.....	53°	
	5	91	952°	1746°	Slowly cooled in tube-muffle to 880° C	"	.....	66°	
	11	97	952°	1746°	Slowly cooled in tube-muffle to 808° C	"	.....	55°	
	10	96	952°	1746°	Slowly cooled in tube-muffle to 743° C	"	.....	26°	
	6	92	952°	1746°	Slowly cooled in tube-muffle to 664° C	"	.....	25°	
	7	93	952°	1746°	Slowly cooled in tube-muffle to 592° C	"	.....	18°	
V. Repeatedly heated and quenched.	12	98	952°	1746°	Quenched from 952° C. twice	"	.....	90°	
	13	99	952°	1746°	Quenched from 952° C. thrice	"	.....	82°	
VI. Quenched after very sudden heating.	B^1	115	White.		.....	"	.....	40°	
	B^2	115	Light yellow.		Quenched.	"	.....	45°	
	C	115	White.		Before quenching cooled in the air for 1 min.	"	.....	29°	
	D	115	"		Before quenching cooled in the air for 30sec.	"	.....	31°	
	D^a	115	"		Before quenching cooled in the air for 30sec.	"	.....	70°	
.....	A	115	White.		Cooled slowly, reheated to 1050°+ quenched	"	185°	208°	

The bars which are said to have been heated to 1050° were heated in a coke-fired muffle till a lump of copper which stood among them melted.

The bars of group VI. were heated in direct contact with a hot coke fire.

All the rest were heated in the tube-muffle.

Bars A^{23}, A^{24} and A^{25} were quenched intermittently, as follows: A^{25} was drawn from the muffle, immersed and moved up and down in cold water for two seconds, withdrawn and held in the air for two seconds, re-immersed for two seconds, etc., etc. Bars A^{24} and A^{23} were treated in the same way, except that the intervals were of three seconds and five seconds respectively.

Bar A^{22} was quenched intermittently in oil.

Bar 12 was heated to 952° C., quenched in cold water, reheated to 952° C., and requenched in cold water.

Bar 13 was thus heated and quenched three times.

TABLE 6.—*Influence of Heat-treatment on Rolled Manganese-Steel Strips, $\frac{3}{4}$-inch × $\frac{3}{16}$-inch × 6 Inches Long.*

SERIES 11.

GROUP.	Bar No.	Laboratory Page.	HEAT TREATMENT. Heated to. C.	Heated to. F.	Further Treatment.	BENDING TEST. Broke at °	Maximum aperture, inches.
	I.	II.	III.	IV.	V.	VI.	VII.
I. Heated and quenched.	20	270	Light red.		Quenched directly in cold water.	.....	0.25
	1	104	952°	1746°		.....	0.44
	8	111	808	1486		.....	0.53
	9	112	664	1226		147°	.....
II. Twice heated and quenched	2	105	952	1746	Quenched, reheated to 808° / 664 / 542 and quenched again.	183	.....
	3	106	952	1746		110	.....
	4	107	952	1746		176	.....
III.	22	270	Low yellow.		Thrice heated to low yellow and quenched.	.....	0.22
IV.	21	270	Light red.		Cooled in ashes.	.....	0.50*
Cooled Slowly.	23	307	1002° C.		" extremely slowly.	114*	Snapped instead of tearing.
V. Quenched then cooled slowly.	5	108	952	1746	Quenched, reheated to 808° C / 664 / 549 and cooled slowly.	144	.....
	6	109	952	1746		89	.....
	7	110	952	1746		164	.....
	10	113	952	1746	Cooled slowly, reheated to 952° and quenched.	.....	0.37

* These bars lost enough of their thickness by oxidation to increase their flexibility seriously. The bends here recorded are therefore abnormally large.

[NOTE TO TABLE 6.—Many bars did not break when they were bent so far that their ends met. These bars were then further flattened in the press till they broke, and the widest aperture was then measured and its width recorded in column 7. The smaller this aperture, the tougher is the bar.]

from which we now quench; hence the injury in this case reaches a maximum with a certain degree of reheating, between 542° C. and 808° C. If the temperature to which we reheat be above that of maximum harm, the benefit caused by the re-quenching increases faster with further rise in temperature than the injury caused by the reheating itself does; and hence the higher we reheat the better.

If, however, the metal is to be reheated to some relatively low temperature, some temperature below that of maximum harm, then the lower this temperature the better. For in this range below that of maximum harm, the injury due to reheating increases faster with the temperature, than the benefit due to the quenching does.

Here we have another suggestion that it is in the higher ranges of temperature rather than in the lower, that slow cooling injures manganese-steel and sudden cooling benefits it.

(8) *Fissibility.*—These experiments brought out strongly one of the striking peculiarities of maganese-steel, its non-fissibility; cracks do not propagate across it readily. It often happened in the bending test that the bar would crack at many places long before rupture. The first crack, instead of causing rupture, would open a little way, and then seem to cease opening, while other cracks would open later. I have often noticed this in the regular bending tests in the manufacture of this material, at the Taylor Iron and Steel Works; but a careful study of this peculiarity has not yet been made.

III.—Study of the Critical Points of Carbon-Steel by Quenching and by Thermal Curves.

A.—*The Retardations.*

(9) *Introduction.*—If high-carbon tool-steel be heated to very dull redness and then suddenly cooled, for instance by quenching in water, it is not thereby considerably hardened;* but such sudden cooling, if it be from bright redness, hardens the metal intensely. In the former case the steel can be scratched with a knife, in the latter it will scratch glass. The hardening power is thus acquired between low and high redness. As steel is gradually heated other striking changes occur in this range of temperature. The carbon changes from one state of combination with the iron known as that of "hardening-carbon," to another known as the "non-hardening" or "cement" state. "The rise of temperature is retarded or perhaps even reversed; the expansion is checked and reversed, so that the

* When we say that sudden cooling hardens steel we usually have in mind not only its effect on the hardness proper, but also on the other physical properties, especially on ductility, tenacity and the elastic limit. The "hardening-power," the cause which underlies hardening, affects these properties jointly, and increase of hardness is but one specific effect of hardening in its usual generic sense. The nomenclature is confusing and demands improvement. I will try to use the verb "to harden" and the verbal noun "hardening" only in their generic sense, the abstract noun "hardness" in its specific sense.

metal contracts momentarily, and then re-expands; a dry crackling sound is heard; the thermo-electric deportment becomes anomalous; the coercive force and the power of being rendered a *temporary* magnet (whether by electric current or by another magnet) and hence of being attracted by the magnet, almost disappear, the latter at least through a series of distinct and separate diminutions; and the specific heat (as inferred from the quantity of heat given out by the metal when immersed in a calorimeter) suddenly increases, remaining astonishingly high from 660° to 720° C., when it again descends somewhat, but remains about twice as great as at the ordinary temperature. The changes in attraction by the magnet and in specific heat have been directly proved to be simultaneous;"* and in the present paper we shall inquire whether certain of these other phenomena occur together.

As the metal again cools slowly the reverse changes occur; the magnetic properties are regained and the hardening power is lost; the specific heat falls suddenly; the carbon changes back to its original condition; and heat is evolved on reaching a certain critical point so suddenly as to raise the temperature visibly. The phenomena in cooling occur at temperatures lower than those of the reverse ones in heating.

In the experiments which form the basis of the present division I studied three only of these different classes of phenomena, viz., (A) the sudden spontaneous absorption and evolution of heat which occur during heating and cooling; (B) the acquisition and loss of the hardening power; and (C) the changes in the condition of the carbon. My original object was to learn how and at what temperatures the hardening power is acquired and lost. Later I enlarged the scope of the inquiry, aiming incidentally to ascertain eventually whether what I may call the "carbon theory" of the hardening of steel was true, *i.e.*, whether the reason why suddenly-cooled steel is hard while slowly-cooled steel is soft, is that the sudden cooling denies the time which is needed for the spontaneous passage of the carbon from the hardening to the non-hardening or cement state; while the slow cooling affords sufficient time.

As steps towards the solution of this, I set before myself the following questions: (*a*) Does the change of carbon-condition invariably accompany, and is it always proportional to the loss and gain of the hardening power? This, if true, would be a nearly conclusive affirmative answer to my main question.

* *The Metallurgy of Steel*, the author, p. 184.

(*b*) Do the sudden spontaneous absorption and evolution of heat during heating and cooling correspond always and accurately to the acquisition and loss of the hardening power, or can they be divorced from it?

So marked a change as occurs in the chemical condition of carbon should produce some thermal phenomena. If the carbon-changes do not correspond exactly to the loss and gain of the hardening power, then there should be some heat-evolution or absorption which does not correspond with this loss and gain of the hardening power. Hence if all the thermal phenomena tally exactly with the loss and gain of the hardening power, we naturally infer that the changes of carbon-condition do also; and we thus infer an affirmative answer to our second question and through it to our first. The direct evidence as to the correspondence between the carbon-change and the loss of the hardening-power is given in Part IV.

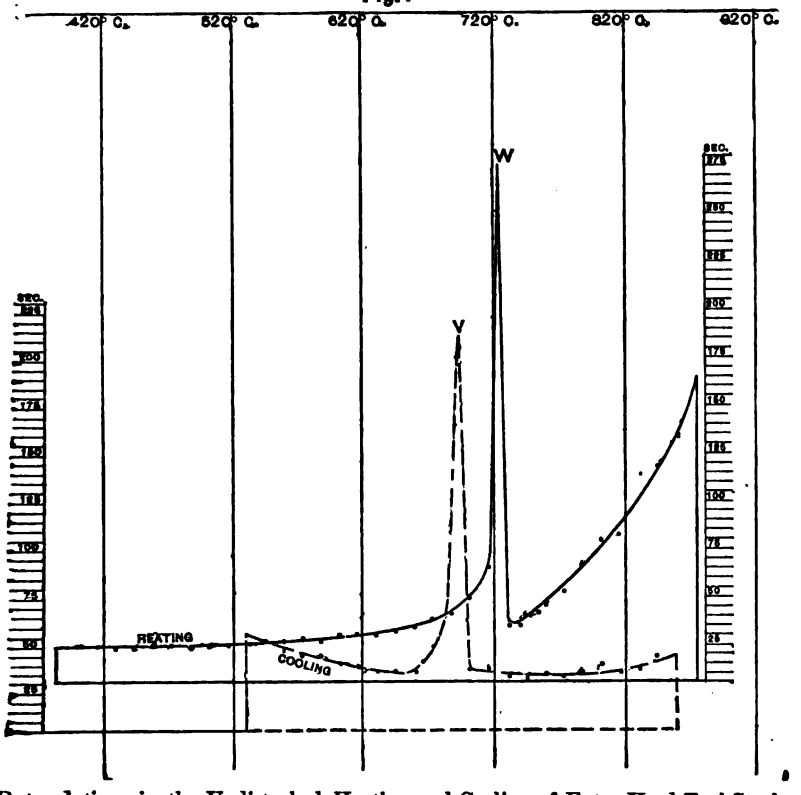
As a preliminary step let us study in some detail the thermal phenomena, before seeking the relation between them and the acquisition and loss of the hardening-power.

(10) *Mode of Studying the Thermal Phenomena.*—If we heat a bar of copper by a flame of constant strength, and note carefully the interval of time occupied in passing from each degree to the next higher degree, we find that these intervals increase regularly, *i.e.*, that the bar heats more and more slowly as its temperature approaches that of the flame. If we substitute a bar of steel for one of copper, we find that these intervals indeed increase regularly up to a certain point, when the rise of temperature is suddenly and in most cases greatly retarded or even completely arrested. After this the rise of temperature is resumed with intervals which, as in the case of copper, increase regularly as the temperature of the bar nears that of the surrounding objects; though other similar retardations may recur as the temperature rises farther. So if we cool a bar of steel slowly, the fall of temperature is greatly retarded when it reaches a certain point in dull redness. If the steel contains much carbon, and if certain favoring conditions be maintained, the temperature, after descending regularly, suddenly rises spontaneously and abruptly, remains stationary awhile, and then redescends. This spontaneous reheating is known as the "after-glow," "recalescence," or "Gore's phenomenon" from the name of its discoverer.

These retardations and this recalescense are the thermal phenomena which we are to examine. Clearly each retardation means that some change which evolves or absorbs heat is occurring within the metal.

A few typical examples of the rate at which the temperature changes during undisturbed heating and cooling, including these retardations, are shown graphically in Figs. 1 and 2 to 8 inclusive, in which abscissæ (horizontal distances) indicate the temperature in degrees centigrade, and ordinates (vertical distances) indicate the interval of time occupied in passing from each degree to the next higher or lower degree, as the case may be.

Fig. 1



Retardations in the Undisturbed Heating and Cooling of Extra-Hard Tool-Steel. Series 17. From Experiments in the Tube-Muffle.

These intervals were measured by the second-hand of a clock. As the changes of temperature were usually very slow, a very fair degree of accuracy was obtained by having three observers work together, one calling out at the instant when each division of the galvanometer-scale was passed, a second calling out the time, and a third recording. In the ranges where retardations occur, the inter-

vals were recorded for every 1.4° C. of rise or fall of temperature; elsewhere for every 14° C.

(11) *Nomenclature.*—Chernoff early detected critical, or at least important, points or ranges of temperature which he called *a* and *b*. Osmond adopts his name *a*, by which I understand that he designates at once a retardation and the change which causes it. Retardation-points which occur during *heating*, *i.e.*, those at which the regularity of the *rise* of temperature is broken, he calls a_c (*a chauffant?*); those which occur during *cooling* he calls a_r (*a refroidissant?*). He further discriminates between the different retardation-points which exist during one and the same heating or cooling by calling the lowest one a_{c1} or a_{r1}; the next higher, a_{c2} or a_{r2}; the next higher, a_{c3} and a_{r3}, etc.

An objection to this nomenclature is that, by implication, it specifically identifies each individual retardation of cooling as corresponding to some definite individual retardation of rising temperature; and it further specifically identifies the individual retardations of one steel with those of others.

In my opinion, such close identification is not justified by our present knowledge; it tends to give currency to hypotheses which as yet rest on too slender foundations, and to introduce preconceptions.

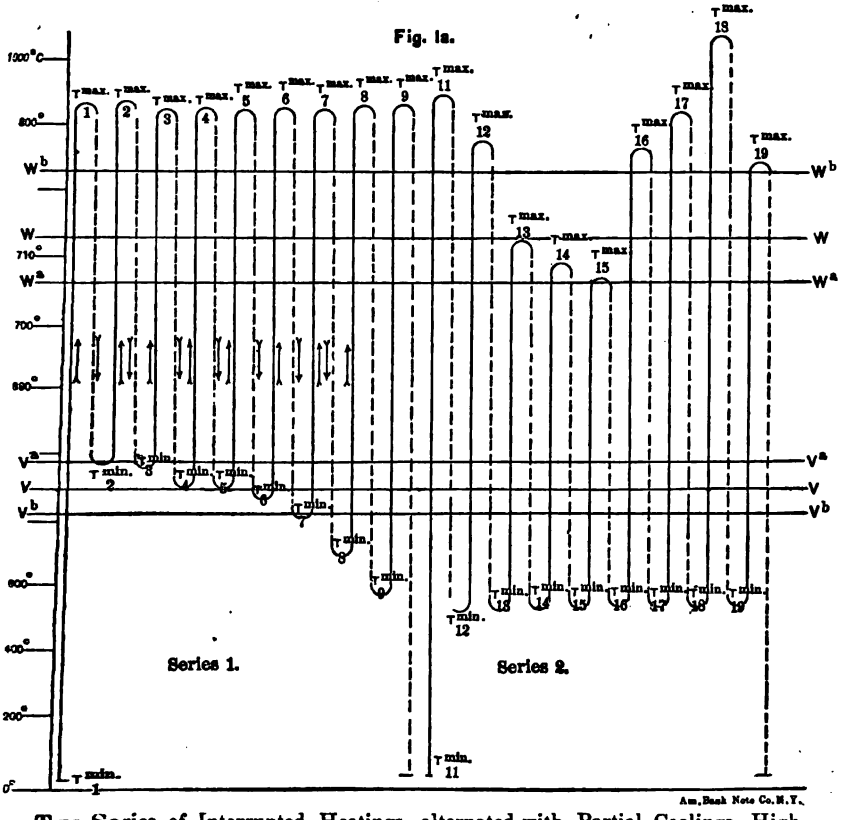
Two of these retardations, one in heating and one in cooling, indeed seem so constant in position, both in different classes of steel and for different conditions of heating and cooling, that we may wisely assign to each a specific name; but it is more prudent to select for them names that do not imply that they are related to each other, because such an implication begs one of the very questions which our experiments aim to examine.

I have therefore adopted Brinnell's names, V and W, for the temperatures at which these particular retardations occur, W for the temperature of retardation during heating, V for that during cooling. Chernoff's name, *a*, certainly has the advantage of priority, but he gave us no name for the retardation-point during cooling. To use his name, *a*, might give some support to Osmond's theories, while Brinnell's names, V and W, make no theoretical implications; indeed, they are already nearly as well and widely known as Chernoff's. Were further justification needed, the incomparably greater thoroughness and value of Brinnell's work in my opinion would give it.

W and V are names of temperatures, not of changes nor of retardations at those temperatures. I call these the V-change, the W-retardation, etc.

At present I make no assumption as to whether each change is a single one, or whether it consists of two or more distinct or even separable changes.

(12) *Are the V-change and the W-change Reversals of Each Other?* —In the study of these thermal phenomena the first question which I attempt to answer is this: Is the change which at V retards the cooling a reversal of that change which at W retards the rise of temperature? The plan followed in studying this question incidentally threw much light on the mode in which these two occur. To facilitate description of the experiments let me define certain symbols.



Two Series of Interrupted Heatings, alternated with Partial Coolings, High-Carbon Tool-Steel of Series 10.

NOTE.—The vertical scale is exaggerated in the range which contains the critical points, V and W; and in this range the positions of T^{max} and T^{min} are given only approximately, because the absolute positions of V and W are not constant. Full lines are heatings; broken lines, coolings.

(13) *Definitions.*—Suppose that, as sketched in Fig. 1A, I heat a

bar to a certain temperature, then cool it partly, arresting the cooling while the bar is still very hot, and again heat it to some high temperature; that I again partly cool it to some other but still moderately high temperature, and again heat it a third time to some third maximum point, and so on. Let us call the temperature from which each cooling begins, *i.e.*, the highest temperature which the preceding heating reached, the T^{max} of that cooling; and let us call the temperature from which each heating starts, *i.e.*, the lowest temperature reached in the preceding cooling, the T^{min} of that heating. Thus, T^{min} is the initial temperature of each heating, and T^{max} that of each cooling.

If the V- or the W-retardation be not confined each to a single point, but be spread out over a range of temperature, let us, as indicated in Fig. 1*a*, call the point above V, at which the V-retardation begins, V^a, and the point below V, at which it ends, V^b; and let us call the point below W, at which the W-retardation begins, W^a, and that above W, at which it ends, W^b. Then the V-range reaches from V^a *down* to V^b, and the W-range from W^a *up* to W^b. W, then, will be simply the point of greatest retardation in heating, and V that of greatest retardation in cooling.

To measure R, the *amount of retardation*, we subtract from the time actually occupied in passing through the V-range or W-range the time which would have been occupied had the rate of heating or cooling been the same in that range as above and below it.

(14) *Prediction.*—If now, the V-change is a reversal of the W-change, then we should expect that, when by heating our metal past W we have caused the W-change to occur, it could not occur again till it has first been reversed by the occurrence of the V-change, *i.e.*, till the metal has cooled at least into the V-range. Hence, on this same supposition, in heating through the W-range a retardation should occur if T^{min} is below V^a, but not if it is above V^a; and, by like reasoning, in cooling through the V-range, a retardation should occur if T^{max} has been higher than W^a, but not if it has been below W^a.

Further, if in a continuous series of alternate heatings and partial coolings we carry T^{min} progressively lower and lower, we should in our heatings find more and more marked retardations in the W-range till T^{min} has descended as low as V^b, but further lowering T^{min} should not increase this retardation. Conversely, if in such a series we carry T^{max} progressively higher and higher, the retardations which occur in cooling through the V-range should succes-

sively increase, till T^{max} reaches W^b, but further elevating T^{max} should not further increase this retardation.

Further still, the descent of T^{min} through those parts of the V-range in which the retardation in cooling is most marked, should have the greatest effect in increasing the retardation in the following heating; and conversely the ascent of T^{max} through those parts of the W-range, in which the retardation in heating is greatest, should increase most rapidly the retardation in the V-range in the following cooling.

In short, in either phase (heating or cooling) the effect of any variation of the initial temperature on the retardation should be proportional to the retardation in the opposite phase in the range covered by that variation.

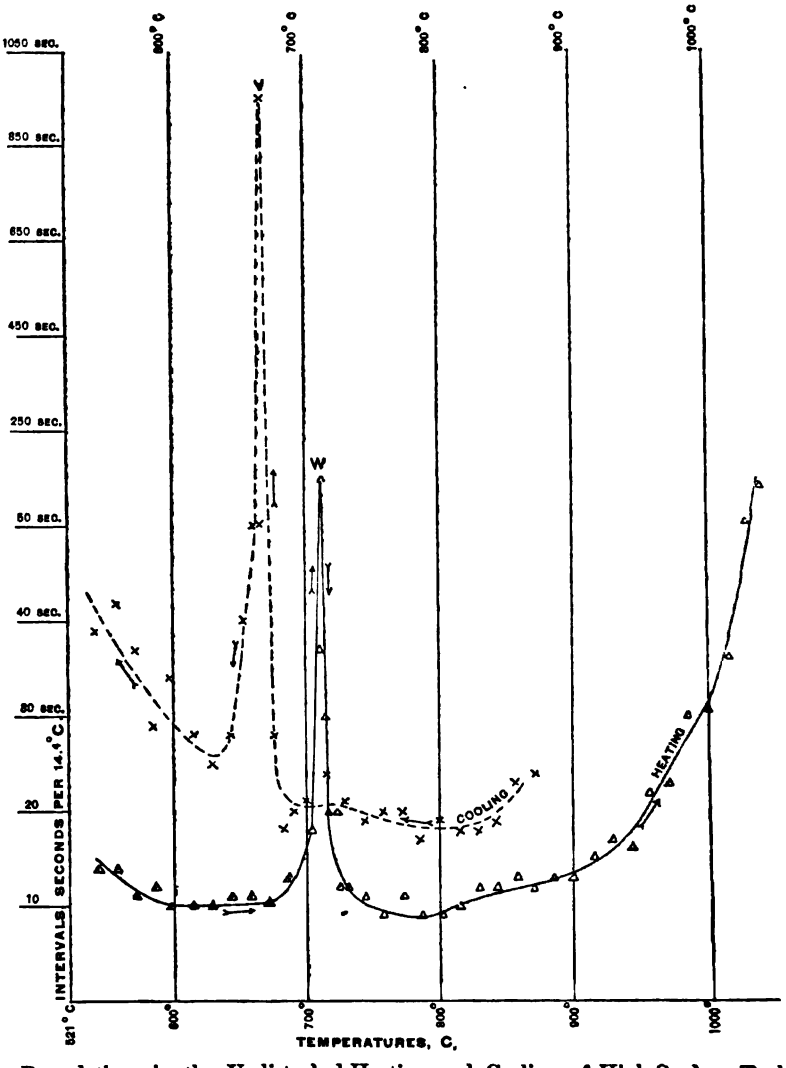
Let it be very clearly grasped that the object of the experiments I am about to describe is to show *whether the position of the initial temperature* (T^{min} *or* T^{max}) *of each heating or cooling, influences the retardation in that heating or cooling in the way which I have here outlined*, and which would show that the V-change and the W-change are reversals of each other. Unless it be clearly understood that we are studying the influence of the initial temperature, T^{min} or T^{max}, on these retardations, what follows in (15) to (24) will be meaningless.

(15) *Verification.*—In order to test these predictions, two such series of heatings and coolings were carried out somewhat as sketched in Fig. 1*a**, and their results are condensed in Table 7. Bars of high carbon tool-steel of Series 10, with about 1.20 per cent. of carbon, were selected, because this metal gives very marked retardations at V and W, as Fig. 2 shows.

In the first series (heatings 1 to 9 inclusive) T^{max}, the initial temperature of the coolings, varied relatively little, while T^{min}, the initial temperature of the heatings, was purposely varied through and beyond the V-range; this was to show the influence of prior exposure to different parts of the V-range on the retardation in the W-range during the following heating. In the second series (heatings 11 to 19 inclusive) these conditions were reversed; T^{min} was nearly constant, while T^{max} was purposely varied through and beyond the W-range, so that we might learn how the retardation in the V-range in cooling is affected by prior exposure to different parts of the W-range.

* This figure represents only roughly the course of these heatings and coolings, if for no other reason, because the position of V changes much.

Fig. 2.



Retardations in the Undisturbed Heating and Cooling of High-Carbon Tool-Steel, Series 10. From Experiments in a Forquignon Furnace.

NOTE.—The vertical scale above the 50-second line is only 1-20th as large as below it.

Before attempting to verify our predictions, let us first learn the positions of our several points, V, W, V^a, V^b, W^a and W^b, as indicated by the retardations; and let us ascertain the relative strength of the retardations in different parts of the V-range and of the W-

and Cooling Hea

ion	Position of V-E			
les-e, s C.	Upper Limit Va.		Great's Retard. V.	
Degrees risen.	Above 0° C.	Relation to V.	Above 0° C.	
		Deg.	Deg.	
			670°	
10	678	V + 9	670	
10			670	
10	678	V + 7	671	
10	678	V + 6	673	
10	680	V + 6	674	
9	681	V + 4	677	
7	680	V + 6	674	
9	680	V + 10	670	
10	680	V + 10	670	
8	680	V + 1	678	
4	680	V + 3	677	
1	?	?	686	
	?	?	680	
	?	?	678	
	?	?	675	

T min.. for heating
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range. I will show later that we should expect the position and distribution of these retardations to be affected by the rate at which we heat or cool the metal. Because the V-retardation should be slight, and hence abnormal in quantity, when T^{max} has been well below W, and the W-retardation should in like manner be abnormal in quantity when T^{min} is well above V; and because, in each case, the abnormal quantity is likely to lead to abnormal position; therefore we should expect to learn the normal position and distribution of these retardations through studying those heatings in which T^{min} is below V^b and those coolings in which T^{max} is above W^b; and these we will especially study.

(16) *The Position of the W-Range.*—When the heating starts from below V (as happens in every case except heatings 2 to 5 inclusive), the positions of W and W^a are surprisingly constant. With a single exception, W lies uniformly between 711° and 716°, and W^a between 704° and 707°, a constancy which is surprising, in view of the serious sources of error. W^a here lies between W—6° and W—10.°

As T^{min} in heatings 3, 4 and 5 of Table 7 is raised to and above V, though the position of W^a remains nearly constant, that of W varies strangely, yet not very widely, its highest point being 717° to 719°, and its lowest between 709° and 710°, a total variation of only some 9° or 10° C. Here a normal position for W is not to be expected.

As might be expected, the W-retardation ends more gradually and less regularly than it begins, and in most cases in the first series I cannot identify W^b confidently. In six of the heatings of the second series, however, W^b is tolerably well-marked, and more constant than we could expect, lying between 723° and 726°, or from 7° to 12° C. above W. In other cases it seems to be slightly more than 14° above W, and in still others, a faint retardation seems to extend nearly 30° above W. But I find no clear evidence that there is beyond W + 14° any retardation sufficient to be of importance for our present purpose.

(17) *The Position of the V-Range* varies more than that of the W-range. Its greatest constancy is in the position of V^a, which, in the ten cases in which T^{max} is higher than W + 18° and in which V^a is recognizable, lies between 678° and 681° C.; yet, in these same cases, the position of V varies some 8° C., lying between 670° and 678°.

The position of V^a relatively to that of V, in the ten cases in which it is recognizable, lies between V + 1° and V + 10°.

Taking all the cases in which V is recognizable, we find a total

variation of 16° C., viz., from 670° to 686°. The constancy of W and W^a argues that the variation of V is not due to observational error.

Just as W^b, the end of the W-retardation, is less marked and less constant than W^a and W, so V^b, the end of the V-retardation, is less marked and less constant than V^a and V. In the ten cases in which V^b seems to be recognizable, it varies 30° C., viz., from 645 to 675°, and from V—1° to V—24°. Occasionally there were strong indications of retardation at lower points, even below 600° C.

I find no clear evidence that these considerable variations in the positions of V and V^b are due to variations in the position of T^{max}, the initial temperature of the cooling; their positions seem about as irregular in coolings whose initial temperature is far above W, as in those in which T^{max} is near W. Indeed, even in the five cases in the first series of Table 7 (coolings 5, 6, 7, 8 and 9) in which T^{max} is practically constant, V varies 7° C., and V^b apparently varies 17° C.

To sum up, the W-range normally runs from about 706° C. to about 723° C., covering from about 14° to about 20° C. Its point of maximum retardation, W, lies a little below the middle of the range, at about 713° C.

The V-range begins at about 679° C., and apparently ends between 645° and 674°, thus covering from about 5° to about 34°. But there are indications of further retardation at still lower points. Its point of greatest retardation, V, lies usually well above the middle of the range, on an average at 675°; but its position varies considerably.

There is thus a distance of about 27° between W^a, the lower edge of the W-range, and V^a, the upper edge of the V-range.

(18) *Distribution of the Retardations.*—Let us next learn how each retardation begins and ends, to what extent it is concentrated at the point of maximum retardation (V or W), and, in short, in what manner it is distributed through its range. Only a rough approximation can be made.

The distribution of the W-retardation varies greatly, while that of the V-retardation is, in one respect, much more constant. Only from 22 to 47 per cent. of the W-retardation occurs at W; always a considerable part of it, and often nearly one-third of it, takes place before W is reached, while nearly always at least one-quarter, and sometimes about half of it, occurs after W is passed.

The V-retardation, however, is to a greater degree concentrated at

V itself, where at least 66 per cent., and often 90 per cent., of the total retardation occurs. Of the small remaining part of the retardation, more usually occurs below than above V.

The W-retardation usually begins suddenly; the rise of temperature slackens suddenly to a rather regular slow gait, which is kept up usually with little change until W itself is reached, when a complete and sudden arrest occurs; after this the immediately preceding slow gait is soon resumed, and accelerates gradually till the normal rate of heating is reached.

The V-retardation begins much like the W-retardation, bringing the cooling to a slow gait, which is preserved often with no important change till V itself is reached. Then the cooling is abruptly arrested, and the temperature spontaneously rises, usually by from 7° to 10°, remains stationary for from 23 to 43 seconds, and redescends to V, in general more slowly than it had risen. From V to V^b the cooling accelerates gradually and rather irregularly.

Where T^{max} is not above W, and where T^{min} is not below V, these relations are even more irregular, with a tendency to increase the percentage of the total retardation which occurs before the point of maximum retardation is reached.

I here tabulate these numbers:

TABLE 7a.—*Estimated Distribution of the V- and W-Retardations, in Percentages, Normal Cases only.*

	W - Retardation.			V - Retardation.		
	Below W. Per ct.	At W. Per ct.	Above W. Per ct.	Above V. Per ct.	At V. Per ct.	Below V. Per ct.
Minimum.....	14	22	24	1	66	4
Maximum.....	40	47	63	9	95	26
Average.....	31	37	32	5	83	12

This table may understate the percentage of the total V-retardation which occurs below V, because, in addition to the retardation clearly observed below V, there are suggestions of further retardation at still lower temperatures.

On seeking to verify the prediction made in (14) as to the influence of the initial temperature on the retardations—the prediction that the amount of retardation which will occur in either phase

will be proportional to that which we have permitted to occur in the preceding and opposite phase—we must first admit that the accurate correspondence which we might there have expected, now cannot be hoped for; because we have now seen that the distribution of these retardations varies much, and in a way not understood. Thus, we have seen, that at times as much as 26 per cent. of the total retardation in cooling occurs after the temperature has sunk below V, at others, only 4 per cent. V^a is now but 1°, now 10° above V; here the retardation appears to have ended completely when the temperature has descended 1° below V; there it continues till the temperature has fallen 24° below V.

Hence, when the cooling is interrupted, now before reaching V^b, now even before reaching V, we cannot readily tell where V^b or V would have been, and hence how far above them the cooling has been interrupted; nor can we tell what the total retardation would have been, nor what proportion of it has already occurred, without a most careful record of the progress of the individual cooling. Indeed, it is not certain that such a record would furnish elements sufficient for the construction of the cooling through the still unexpired part of the V-range. For instance, had cooling No. 18 of Table 7 been interrupted at 657°, we might easily have inferred from the regularity with which it had gone on between 673° and 657°, and from the analogy of other cases, that the retardation was very nearly at an end; whereas in fact a very striking and exceptional retardation actually takes place between 657° and 655°. Let this teach caution in drawing inferences.

This admitted, let us see what rough correspondence we can detect, and let us first seek the influence of T^{min} on the W-retardation in heating.

(19) *Influence of T^{min} on the W-retardation.*—To show this, I here condense in Table 8 some numbers from Table 7:

Here, as T^{min}, progressively descending, appears* to recede from V^a and to near V (heatings 2 and 3), the W-retardation from being a mere suggestion becomes distinctly recognizable, though still slight; this agrees with our prediction, because the retardation in cooling is slight between V^a and V.

As T^{min} progressively descends slightly further (heatings 4, 5, and 6) to the beginning and end of V-retardation, W-retardation now pro-

* I say "appears," because we cannot now be sure how far T^{min} is above V; and this because the position of V shifts according to some law now unknown.

TABLE 8.—*Influence of T^{min} on Retardation in W-Range, in Heating.*

Position of Critical Points.	Number of Heating.	T^{min}.		R, Total Retardation in W-Range, Seconds.
		Above 0 C.	Relative to V.	
V^a				
	2	678°	+ 11° (?)	
	3	671	+ 4° (?)	4 ±
V	4	670	0	16
	5	670	0	30
V^b	6	667	— 3	43
	7	655°	— 16	50
	8	635	— 38	49
	9	565	— 109	49
	18	521°	— 149	33
	11	22	— 648 ±	49
	17	521	— 156	39
	12	518	— 168	38
	16	521	— 154	31
	19	528	— 146	49

gressively increases greatly and abruptly, from about 4″ to 16″, and then to 30″ and 43″, though T^{min} descends altogether only 7° ; this is as we should expect, because the retardation at V is very great in cooling.

As T^{min} further descends (heating 7) towards or to V^b, we have a further considerable increase in the W-retardation, which is as it should be, because there is in cooling a considerable retardation between V and V^b.

As T^{min} further descends (heatings 8 and 9 of the first series, and all those of the second series) from V^b, the W-retardation does not further increase, as our prediction implies, for, in cooling, no retardation was clearly detected below V^b.

If now we compare the distribution of the retardation in cooling between the three stages of the V-range, (1) V^a to V, (2) V, and

(3) V to V^b, with the corresponding fractions of the total retardation at W, caused by the passage of T^{min} through those three stages, we find as close a correspondence as could be expected in view of the sources of error, and of the considerable irregularity in the distribution of the V-retardation between these three stages. Thus, from 1 to 9 per cent. of the V-retardation occurs between V^a and V; and certainly not over 9 per cent. of the total W-retardation is evolved when T^{min} (heatings 2 and 3) descends part way from V^a to V. Further, on an average, 88 per cent. of the V-retardation occurs before the temperature sinks below V, and 12 per cent. during cooling from V to V^b; and correspondingly, we find that 86 per cent. of the W-retardation is caused by lowering T^{min} to barely below V, and 14 per cent. by further lowering it to V^b.

That is to say, assuming that when, at the rate of heating here used, the W-retardation reaches its full development, it should occupy 50 seconds (and it consumes about this in heatings 7, 8, and 9), we find that the 43-second retardation in heating 6 is 86 per cent. of this, and the further increase, caused by further lowering T^{min}, is but 14 per cent., or an increase from 43 to 50 seconds.

The force of this, however, is weakened by the fact that we have apparently much less than 50-seconds retardation in heatings 18, 17, 12, and 16; though this is doubtless due to more rapid application of heat in these four cases.

(20) *Influence of T^{max} on the V-retardation.*—I here condense from Table 7 some numbers through which we trace this influence:

The fact that even when T^{max} is as much as 8° below W (heating 15), there is a slight retardation in cooling, agrees with the observation that W^a is from 6° to 10° below W.

The progressive and considerable, but not sudden, increase in the V-retardation (coolings 15, 14, and 13), as T^{max} rises towards W, harmonizes with the moderately retarded gait of heating from W^a to W. The fact that when T^{max} has risen to within 1° of W (heating 13) the V-retardation is about one-third as great as when T^{max} is above W^b, accords with the fact that about one-third of the total retardation of the W-range occurs below W.

The fact that, by the time that T^{max} has risen to W + 18° (heating 19), the V-retardation has not only increased greatly, but has practically reached its maximum, remaining practically constant with further rise of T^{max}, fulfils our prophecy, because the retardation at W is great, and because W^b is not so high as W + 18°, *i.e.*, because we find no important retardation above W + 18° in heating.

TABLE 8*a*.—*Influence of T^{max} on Retardation in V-Range, in Cooling.*

Position of Critical Points.	Number of Cooling.	T^{max}		R, Total Retardation in V-Range, Seconds.
		Above 0° C.	Relative to W.	
	6	857°	+ 144°	125
	7	857	+ 143	143 +
	8	858	+ 144	137
	9	864	+ 150	127
	1	858	+ 149	.....
	18	1067	+ 355	149
	11	887	+ 172	127
	17	835	+ 121	115
	12	776	+ 61	121
	16	769	+ 54	126
	19	733	+ 18	130
W^b				
W				
	13	714	— 1	45
	14	710	— 5	31
	15	707	— 8	8
W^a				

It remains to learn how great the V-retardation is when T^{max} lies just above W, and also at other points between W and W^b. But it is difficult to conduct the experiment in such a way as to place T^{max} here, because when the temperature once passes W, its rise thence is so fast that it is not readily checked before the temperature has passed W^b.

(21) *To sum up*, while there are certain parts of the field which our experiments have not yet covered, yet, so far as they go, the effect of varying through any range of temperature the initial temperature of either phase (heating or cooling) on the retardation in that phase is roughly proportional to the retardation in that range in the opposite phase. Indeed, the correspondence is closer than we should dare to

expect. This not only argues that the V- and the W-change are simply reversals of each other, no more and no less; but it also indicates that the retardation is a true if rough measure of the degree to which either change occurs in any given range.

(22) *Influence of Rate of Heating or Cooling on the Retardations.*—I must now point out that we might expect the position and distribution of these retardations to depend upon the rapidity with which our furnace conducts heat to or from the metal, *i.e.*, on the rate at which we heat or cool the metal.

To fix our ideas, let us consider the change underlying the V-retardation in cooling. It apparently requires time for its completion. Assuming this for the present, the temperature to which the metal cools before this change is complete will clearly depend on how fast we cool the furnace and through it the metal. If very slowly, then the change will have time to complete itself before the temperature has descended far, and V^b will be relatively high; if somewhat faster, the temperature will have fallen farther by the time when the change has completed itself, and V^b will be relatively low. Clearly, then, if we hasten the cooling we lower V^b; and conversely the slower the cooling the higher will V^b lie. Clearly V^b will descend without limit as the cooling is accelerated, until it reaches so low a temperature that the V-change can no longer go on; in that case this change does not complete itself at all.

Clearly, also, if we have thus depressed the position of V^b by hastening the cooling, we can again raise it by cooling more slowly; but it is uncertain whether we can raise it indefinitely till it coincides with V or even with V^a, or whether there is some limit below V above which we cannot raise V^b.

(23) *Theories of the Progress of the V-change.*—In short, we may conceive two different theories of the progress of this change: (A), that there is just a certain extent to which the V-change can complete itself at each given temperature, so that retarding the cooling would raise V^b and V to certain normal positions, above which they could not be farther raised by still slower cooling; and (B), that once the temperature has fallen to V^a, which is the point at which this change can begin, the degree to which it proceeds is purely and solely a question of time; so that, were the cooling only slow enough, the whole V-change and its whole retardation would take place at V^a. If the latter supposition be true, then the explanation of the recalescence might be something like this: V^a is a fixed point, like the normal freezing point of water; but, just as we can cool water below its

freezing point without completely freezing it, thereby rapidly increasing the strength with which the water tends to freeze, so by a relatively rapid cooling we can carry the metal considerably below V without giving the V-change time to proceed far, strengthening the while the tendency toward this change, which keeps kindling more and more till it bursts into a blaze, with such evolution of heat as actually to recalesce, to raise the temperature of the metal by some 10°, in spite of the continued abstraction of heat by the continued cooling of the furnace.

In (47) I point out certain analogies between the phenomena here observed and those of the surfusion of saline solutions; but let me here note three considerations which point towards the second of the above theories, that the V-change and retardation would complete themselves at V^a were time enough allowed.

I.—We have seen that the positions of V^a and W^a are astonishingly constant, somewhat more so than those of W and W^b, and very much more so than those of V and V^b. This suggests that, while the point at which each change begins is fixed, the degree to which it proceeds at any given temperature varies with the rate of cooling. This is only suggestive.

II.—Osmond's results indicate that V descends as the rapidity of cooling increases. In (56) I point out, however, a possible source of error in his observations. This, too, is only suggestive.

III.—Though in most coolings the V-change progresses but slightly while the temperature is first descending from V^a to V (witness the faint retardation), yet clearly it is not the temperature as such that here limits the progress of this change; for during the recalescence the temperature usually rises from V to above V^a, in three cases 5° or more above it; and during the whole of this rise the V-change is progressing, as is shown by the constant evolution of heat, and as our quenching tests will later prove. This consideration argues more cogently.

(24) *Inertia.*—This last consideration suggests that, while there is an apparently neutral zone of some 27° between V^a and W^a, yet in reality in cooling the V-change and in heating the W-change probably *tend* to set in before these limits, V^a and W^a, are reached, but that this tendency is held in check by what, for lack of a better name, we may call inertia; and that perhaps by some special means we may later be able so to provoke these tendencies as to cause the V- and the W-change to set in earlier than now, *i.e.*, that we may be able to raise V^a and to lower W^a, to shorten the zone

between them, and possibly even to eliminate it. Possibly by jarring, or by altering the magnetic conditions, we may thus provoke these changes.

Indeed, even in the present experiments the beginning of these retardations may have been too gradual to be detected by my measurements, and thus the actual distance between V^a and W^a may be less than I have found it. As to this we must await more delicate measurements. Yet it is quite possible that the beginning is not very gradual; at least we find at the beginning of the recalescence that the retardation increases not gradually but at a great bound. Take for instance cooling No. 11, in which the rate of cooling drops abruptly from 2 seconds per 1.4° C. to 95 seconds. Lest this abruptness be charged to mal-observation, note that even at the recalescence of cooling No. 9, which probably begins more gradually than any of the others, the rate of cooling drops instantly from 7 seconds to 113 seconds per 1.4° C. (The gradual increase of the retardation in coolings 13, 14, and 15 of course does not bear on the present question.)

B.—*Quenching-Experiments.*

(25) *Loss of Hardening-Power at and near V.*—We know that steel is hardened by quenching from a certain red-heat or from any higher temperature; but that if the temperature be allowed to sink below this certain point in redness, quenching will not harden the metal. In short, as steel cools slowly through redness, it loses its hardening-power. Let us learn how and under what conditions this loss occurs, and especially how it is related to the V-change; and to this end let us quench many different pieces of steel, of each of many different grades of hardness, from different temperatures and under different conditions, and examine their ductility by bending tests and by tensile tests. The latter will incidentally inform us how tensile strength is affected by these various quenchings.

The object of this study is to learn whether the V-retardation, and hence the spontaneous evolution of heat which underlies it, corresponds to the loss of the hardening-power; and whether this loss begins at V^a, ends at V^b, and progresses in the different parts of the V-range proportionally to the retardation.

(26) *Difficulty.*—As is pointed out at the end of (18), the progress of the V-retardation varies so much that, without very elaborate and preferably autographic records, we cannot tell accurately what proportion of it has occurred when by quenching we interrupt our

cooling above V^b. Perhaps we cannot tell accurately even with such records; and if we can, it will be with much labor. Further, any inaccuracy in this knowledge implies a like degree of inaccuracy in the correspondence which we may hope to establish between the loss of the hardening-power and the progress of the V-retardation. Let us hope that we may learn to induce these retardations to take place always in the same way.

Partly because of the labor which such elaborate records of the progress of the retardations require, partly because I originally sought only the absolute temperatures at which the hardening-power is acquired and lost, our data are far from full enough to answer completely the question before us.

(27) *Inferences.*—By pushing inquiry along the line we may hope to get valuable side-light on the cause of the hardening of steel. For if the "carbon-theory" be true, *i.e.*, if the reason why sudden cooling hardens steel is, that it denies the time which the spontaneous change of the carbon from the hardening to the non-hardening or cement state requires; and if this change during slow cooling progress *pari passu* with the evolution of heat in the V-retardation, then, comparing steels of different carbon-content, they should be alike when quenched at such stages of the V-retardation as ought to yield the same absolute percentage of hardening carbon. So also, *mutatis mutandis*, with the W-retardation.

Let an example show my meaning. In steel A of 1 per cent. total carbon, the hardening-carbon content should be nearly 1 per cent. after quenching from above V^a; about 0.50 per cent. after quenching when half of the retardation has occurred; and about 0.25 per cent. when the steel is quenched after three-fourths of the retardation has occurred. So steel B of 0.50 per cent. carbon when quenched from above V^a should contain nearly 0.50 per cent. of hardening-carbon, and about 0.25 per cent. if quenched when half the retardation has occurred: and steel C of 0.25 per cent. total carbon should have nearly 0.25 per cent. of hardening-carbon when quenched from above V^a. Then on this theory steel A quenched at mid-retardation should resemble steel B quenched at above V^a, because each should have about 0.50 per cent. of hardening carbon. So steel A quenched when three-fourths of its retardation is over, and steel B quenched when half its retardation is over, should each resemble steel C when quenched from above V^a, for in each there should be about 0.25 per cent. of hardening carbon.

To put it algebraically, let

H = the degree of hardening in any piece of steel:

h = the percentage of hardening-carbon:

r^{v} = the percentage of the total V-retardation which occurred before the metal was quenched:

r^{w} = the percentage of the total W-retardation which occurred before the metal was quenched:

C = the total percentage of carbon.

Then by assumption,

$$[1]\quad H : h = H' : h'.$$

In case of quenching during cooling,

$$[2]\quad h = C\left(1 - \frac{r^{v}}{100}\right).$$

In case of quenching during heating

$$[3]\quad h = C\,\frac{r^{w}}{100}$$

Accurate resemblance is not to be expected, because the different quenching-temperatures, needed to leave like quantities of hardening carbon in unlike steels, should induce different degrees of stress; and because the composition, apart from the like percentages of hardening-carbon, would be unlike. Thus the 1 per cent. carbon steel, quenched when three-fourths of its retardation is over, would contain 0.75 per cent. of cement carbon, or 11 per cent. of cementite if we admit the composition Fe_3C; while the 0.25 per cent. carbon steel quenched from above V^{s} would have none. Yet as cementite is doubtless harder and more brittle than pure iron, its presence in the 1 per cent. carbon steel should in a measure offset the greater stress which the higher quenching-temperature (V^{s}) of the 0.25 per cent. carbon steel should induce.

Again, no matter how rapid the cooling, in the interior of the bar it will always occupy an appreciable length of time; and in this time, which will not be alike in the different steels because of their different quenching-temperatures, different percentages of carbon will slide from the hardening to the cement state. Next, to be accurate, change of carbon from one state to the other should be measured, not by the proportion of the total retardation which has occurred, but by that of the total heat-evolution, which is not exactly proportional to the retardation.

Finally, in addition to the effects of stress and those of the condition of carbon, those of what we may provisionally call structure modify the properties of the metal profoundly. Thus, as we see in Table 18, of two like bars which were cooled slowly from a high temperature, and which therefore presumably had no serious stress and should not differ greatly in the condition of their carbon, No. 44, cooled slowly after heating to 727° C., had 97,992 pounds tenacity per square inch and 32.81 per cent. elongation, while the other, No. 48, treated in exactly the same way except that it was heated to 909° C. instead of 727, had a tenacity of 125,809 pounds per square inch and an elongation of only 12.5 per cent.

We must accumulate more evidence before we can make any general application of this test to the "carbon theory" of the hardening of steel.

(28) *Limitations of the Ductility-tests.*—Let me now point out an important inference from equation [1]. We shall see that rail-steel, quenched at but little above W, has very little ductility: this indicates that some 0.35 per cent. of hardening-carbon suffices to remove ductility almost completely. Our general knowledge indicates that steels containing not much more than this quantity of carbon lose their ductility completely when thus quenched. From this we infer that a relatively small quantity of hardening-carbon, to fix our ideas let us estimate it at 0.50 per cent., suffices to remove ductility completely. If this be true, then, if we quench a series of like bars of high-carbon steel, say that of 1 per cent. of carbon, from progressively higher temperatures, though the degree of hardening should indeed go on increasing till we reach a quenching-temperature so high that all the carbon is in the hardening state; and though tests of the hardness proper should detect the increase of hardness through *this* whole range; yet long before the quenching-temperature reaches the upper limit of this range, enough hardening-carbon should form to destroy ductility completely, and further elevation of the quenching temperature, even if accompanied by further increase of hardness proper, should not further affect the ductility.

In other words, on the "carbon theory," the fact that, when the quenching-temperature in rising reaches a certain point, the ductility vanishes, is not evidence that hardening does not progress with further elevation of the quenching-temperature: nor is the fact that ductility remains *nil* till the progressively descending quenching-temperature reaches a certain point evidence that the loss of the hardening-power does not begin above that point.

(29) *Where is the Hardening-Power Lost?*—Let us now see how the degree of hardening of each series of steel taken by itself is related to the progress of the V-change as revealed by the V-retardation in cooling. Let us first consider the high-carbon steel of Series 10, because we have in (17), (18) and (20) ascertained with some care the position of V, V^a and V^b, and the progress of the retardation in the V-range, for this steel.

(30) *Series* 10.—Several bars of this steel (group IV., Table 20), were heated to about the same temperature, then quenched after partial slow cooling to different points near V. In case of bar 108 the loss of the hardening-power between V^a and the crest of the recalescence,* corresponding according to table 7a to somewhere about 30 per cent of the total retardation, was not enough to give the quenched metal any measurable ductility. In case of bar 109, quenched soon after the middle of the recalescence, when the temperature, after rising 9° spontaneously, began spontaneously to sink, and when probably somewhere about half of the retardation had occurred, the hardening power had so far diminished that the quenched bar took a permanent set of 2° on rupture.

Bar 110, quenched at the end of the recalescence, when the temperature after rising spontaneously 9° from V had re-descended to V, and when by table 7a from 74 to 96 per cent. of the retardation should have occurred, bent 5°.

Bar 111, quenched when the temperature had fallen somewhat below V, and when the retardation should have nearly ended, bent 10.5°: while 112, quenched when the temperature had fallen below V^b, and therefore after the retardation should have become complete, bent 58°, or more than the untreated steel (bar 1), and actually more than one of the bars (No. 12, group VIII.) which was cooled slowly completely. Some might call it "water-annealed." I here recapitulate:

Bar No.	Degrees bent.	Roughly estimated proportion of total retardation which had occurred before quenching, as inferred from table 7a.
8	0	0
108	0	30 per cent.
109	2	50 per cent.
110	5	74 to 96 per cent.
111	10.5	Nearly all.
112	58	All.

* By the "Crest of the Recalescence," I mean the point when the temperature, in rising spontaneously from V, has reached a maximum point, whence it will again shortly descend.

The fact that steel which takes a permanent set of 58° if quenched when the V-retardation is complete, can be bent only 5° if quenched when at least 74 and possibly 96 per cent. of this retardation has taken place, certainly suggests that the loss of the hardening power lags behind the retardation. Yet we should be cautious in admitting this. First, at the end of (18) we saw that we may have over-estimated the percentage of the V-retardation that occurs before the end of the recalescence. Next, admitting that 74 per cent. had occurred when bar 110 was quenched, should it on the "carbon theory" bend more than 5°? It should have about $1.20 \times (1 - \frac{74}{100}) = 0.30$ per cent. of hardening carbon: it should then, according to equation [1], resemble steel of 0.30 per cent. total carbon when this is fully hardened. Should such steel bend more than 5°? The evidence in hand does not imply that it should. Thus in Fig. 4 we find that W^b seems to lie at about 750° for steel of Series 8, which contains about 0.35 per cent. of carbon. Table 17 shows us that this steel (bar 27), quenched from 736°, or when nearly all its carbon should have changed to the hardening state, bends just 5°; bar 26, quenched from above W^b, bends slightly less, only 2°, and this bend gradually falls off to *nil* as, with further rise of temperature, the induced stress doubtless increases. Table 22 shows us that the still softer steel of Series 16, containing about 0.22 per cent. of carbon, when quenched *in brine* from 808°, which to judge from Fig. 5 should be above W^b, and when therefore it should contain nearly 0.22 per cent. of hardening carbon, bends 5°. This case, then, far from opposing the carbon theory, seems rather to support it. But a single case should weigh lightly, unless its teachings be corroborated by other parallel ones. I give it rather as a nucleus for further evidence, and for illustration.

(31) *With Series* 9, soft tool-steel, we get like results (group IV. of Tables 18 and 19). At the beginning of the recalescence, at its crest, and even when the temperature has begun to sink from its crest, so much of the hardening-power remains that the steel, when quenched after slow cooling to these points, has not acquired any measurable ductility, nor has its tensile strength increased (bars 45, 43, and 251). But by the time the quenching-temperature has redescended to V at the end of the recalescence, though the gain in ductility is so slight as to be within the bounds of observational error, the hardening-power has decreased so far as to cause a great increase of tenacity, which, as we should expect in this high-carbon

steel, thus responds earlier to the decrease of hardening than the ductility does. Bar 58, quenched at 7° below V, and therefore probably above V^b, shows a very great gain in ductility; while bar 40, quenched at 69° below V, and therefore probably far below V^b, has greater tensile strength than some of those cooled slowly completely, and far greater ductility than others (Nos. 48 and 57). Some would call it water-annealed.

We thus see that in a series of slow coolings in which all other conditions are substantially constant, by postponing the quenching from the crest to the end of the recalescence, though we thereby lower the quenching-temperature by only 12°, we increase the tenacity by some 20,000 pounds per square inch, while further lowering the quenching-temperature to 69° below V increases the tenacity by less than 12,000 pounds; the increase of tenacity per degree of descent of the quenching-temperature is thus nearly ten times as great in the decline of the recalescence as in the 69° below the recalescence.

SERIES 8.—*Rail-Steel, Quenched Immediately After Moderately Slow Cooling.*

Bar.	Quenching-Temperature.	Permanent Bend.
40, 49 and 53	678° C.	7° to 20°
48	657° C.	18°
47	635° C.	93°

(32) *Series* 8.—Among the bars of the rail-steel of Series 8 which were quenched after cooling at substantially similar rates, we find like results, though they are less conclusive because the position of V was not noted. When the quenching-temperature descends 21°, from 678° to 657° C., there is no very marked change in ductility; when it further descends another 22°, from 657° to 635° C., the permanent bend increases more than four-fold. Comparing this result with Fig. 4, we find that the increase in ductility comes after most of the retardation is past.

(33) *Series* 16.—So with group IV. of the soft steel of Table 22. These bars were heated to about the same temperature, and later quenched after cooling slowly to points near V As the point to which they were cooled descends progressively from 794° C. to 650° C. (1202° F.) near the end of the retardation, their bend increases gradually from 9° and 5° to 81°. When in No. III. the slow cool-

ing was carried but 8° farther, or 9° below V, the bend increased abruptly from 81° to over 190°. Indeed the bar was bent double, so that its ends touched, though it had been quenched in brine.

Thus a decline in the quenching-temperature, even when it is as high as V + 54 (bar 3), increases the ductility; but, while a further descent of 49° increases the bend by only 37°, a still further descent of only 13° C., which passes V, increases it by 135°. The permanent bend thus increases much more rapidly as the quenching-temperature sinks past V, than when it descends through the 49° above V. Nevertheless, the increase in the bend from 9° at 794° C. to 18° at 704° C., is a very strong indication that there is a real and serious loss of the hardening-power in this upper range.

(34) *Series* 15.—The loss of the hardening power of the basic steel of Series 15 cannot be detected readily by means of the bending test; for this steel is so tough that such small bars bend double and are squeezed tight together without cracking, even after quenching in cold brine from a high temperature. One bar which I quenched in a freezing mixture at — 5° C., did crack slightly when bent double, squeezed tight in the press.

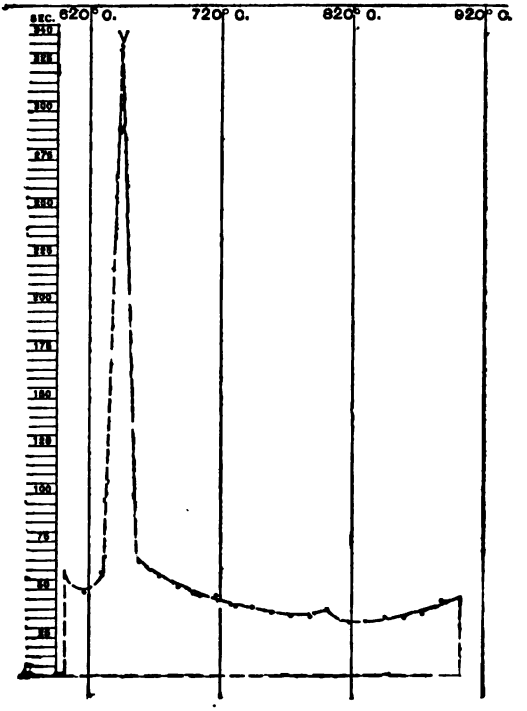
The tensile tests in Table 23 indicate that the ductility of this steel in the quenched state gradually increases as the quenching-temperature sinks. Unfortunately, five of these bars broke outside of the marked area, and the elongation of three others had to be measured in one inch or three inches, instead of in two inches; our record of the elongation is so incomplete that no trustworthy inferences can be drawn from it.

I detect no regular variation in the tenacity as the quenching-temperature gradually descends from 822° to 650°, or apparently slightly above V. But as it sinks gradually along the lower slope of the V-retardation curve, the tenacity now decreases, at first by some 6 per cent., then very rapidly; a descent of the quenching-temperature through only 8° here diminishes the tenacity by 25,162 pounds, or about one-quarter; a further and great fall of 110° lowers the tenacity by very much less, viz., by about 18,000 pounds. Here again the effect of quenching-temperature on tenacity clearly passes a well-marked critical point, which is certainly very near V, though the most marked loss of tenacity seems to come after most of the V-retardation has taken place. The V-retardation in case of this steel is, however, so slight, that I could not confidently identify the position relatively to V of some of these quenching-temperatures.

(35) *Agreement with Thermal Curves.*—I must defer the general

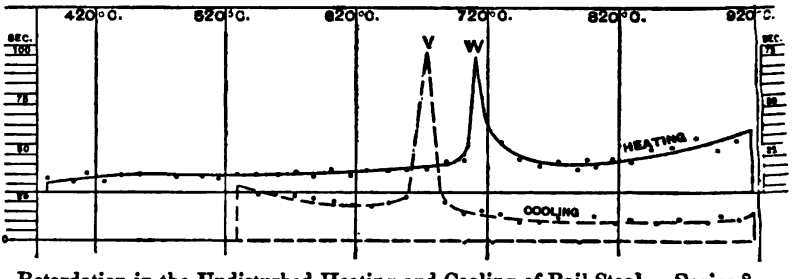
discussion of the correspondence between the retardations, as shewn by thermal curves, and the loss of the hardening-power, confining myself now to two important points.

Fig. 3



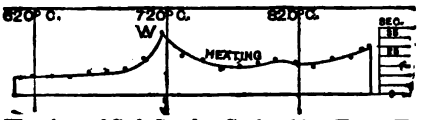
Retardation in Undisturbed Cooling of Rail-Steel. Series 14. From Experiments in the Tube-Muffle.

Fig. 4



Retardation in the Undisturbed Heating and Cooling of Rail-Steel. Series 8. From Experiments in a Forquignon Furnace.

Fig. 5



Retardation in Heating of Soft Steel. Series 16. From Experiments in a Forquignon Furnace.

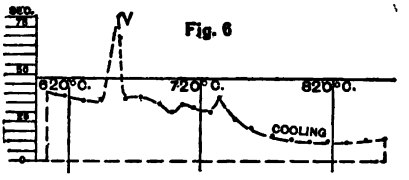
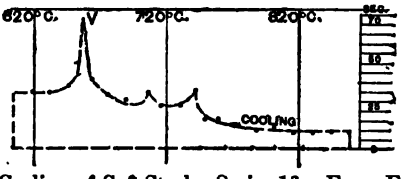


Fig. 6

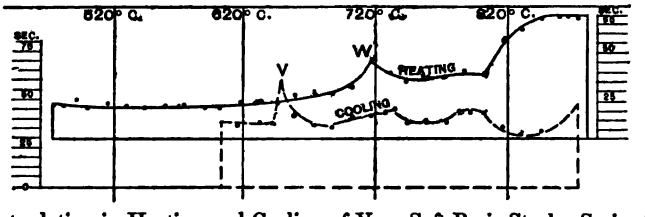
Retardation in Cooling of Soft Steel. Series 16. From Experiments in a Forquignon Furnace.

Fig. 7



Retardation in Cooling of Soft Steel. Series 16. From Experiments in a Forquignon Furnace.

Fig. 8



Retardation in Heating and Cooling of Very Soft Basic Steel. Series 15. From Experiments in the Tube-Muffle.

(36) *The Hardening-Power Apparently Lags.*—In the cooling-curves of the five series of steel which we have just discussed, running from the softest basic steel to very high-carbon tool-steel, we note that each has a marked retardation which reaches a maximum in the neighborhood of 660° C. (1220° F.). These we may temporarily class together as the V-retardation. Now the preceding discussion of the influence of the quenching-temperature on the proper-

ties of the quenched steel shows that, certainly in four and apparently in all five series,* by far the most sudden and marked change in these properties is caused by the descent of the quenching-temperature through the lower slope of the V-retardation curve. In other words, as measured by the tenacity (where observed) and ductility of the quenched metal, the loss of the hardening power for all these steels is most marked after the evolution of heat has passed its maximum, and hence, presumably, after the V-change has begun to slacken; in short, it seems to lag behind the retardation, and hence behind the evolution of heat which underlies it. Indeed, the tool-steels acquired absolutely no ductility till after quenching had been deferred till the crest of the recalescence was reached.

This fact, if shown only by ductility tests, might be explained away on the carbon theory in the way indicated in (28). But in Series 9 the tensile strength also gives indications of like lagging. At any rate, for the present I insist only on the fact that, if there be any discrepancy between the thermal curves and the loss of the hardening-power, it is that this loss lags behind the retardation; certainly there is no evidence suggesting that it outruns or precedes the V-retardation.

(37) *The Upper Retardations.*—Next, when we come to the softer steels, which have noticeable upper retardations, the loss of the hardening-power which accompanies those upper retardations is not greater in proportion to their size than the loss at the lower or V-retardation. Let us consider this for Series 16, soft steel, and Series 15, very soft basic steel.

(37*a*) *Series* 16 (Table 22 and Fig. 6).—The fact that there is no loss but even a slight apparent gain of the hardening-power as the quenching-temperature sinks from 794° to 756° agrees with the fact that there is no considerable retardation in this range (Fig. 6).

The loss of the hardening-power implied by the increase of the permanent bend from 5° to 26° as the quenching-temperature sinks 92°, from 756° to 664°, which is near the beginning of the marked V-retardation, harmonizes with the very noticeable retardation in this range at about 734°. The further great loss of the hardening-power implied by the increase of the permanent bend from 26° to 190° as the temperature further sinks 22° and passes V, corresponds to the relatively great retardation at V. Now, while the upper retardations are much less sharp than that at V, yet they seem to imply

* We have not enough data with regard to the rail-steel of Series 8 to warrant speaking positively as to its behavior.

at least half as much actual retardation as it does. But it can hardly be claimed that the loss of the hardening-power in these upper ranges, increasing the permanent bend only from 5° to 26°, is more than half of the loss in the V-range, which increases this bend from 26° to 190°.

(37*b*) *Series* 15.—In the cooling curve of the soft basic steel, Fig. 8, there certainly seem to be two considerable upper retardations; the one in the neighborhood of 790° is very noticeable. But when we turn to Table 23, we do not find a corresponding loss of the hardening-power; this loss seems to occur wholly in the neighborhood of V. On examining the rate of cooling of other bars of this same steel, I find that the retardation at this upper point is often faint, and sometimes not to be clearly detected at all.* This irregularity in the amount of retardation in the upper ranges goes to explain the apparently aimless way in which the tenacity wanders about, varying from 90,319 pounds to 100,705 as the quenching-temperature descends. For instance, bar 24, which seems to have lost none of its hardening-power though the quenching-temperature had been lowered to 661°, shows no recognizable retardation in the upper ranges.

But, while further study must decide whether the loss of the hardening-power does tally closely with the upper retardations, our present evidence indicates that, if there be any discrepancy, it is that the loss of the hardening-power is greater in proportion to the retardation at V than in the upper ranges.

(38) *Relation Between Carbon-Content and Rapidity of V-Change.*—In Tables 9 and 10 I condense some of these results, in order to study the relation between the proportion of carbon in the steel and the rapidity with which the V-change takes place.

(39) *Time Needed For V-Change.*—Up to this point in our study of the progress of the V-change between V^a and V^b, we have considered the effect of temperature only.

But the brittleness of steel quenched at, or even below V, evidently arises, at least in part, from too quick cooling through this range of temperature; in moderately slow cooling the metal does

* It might be thought that these slight upper retardations, or at least one of them, was due to a retardation, not in the bars under examination, but in the iron tube M, Fig. 10. But were this the case, then like retardations should occur with the hard steels as well; but they do not. Moreover, direct experiments with the empty furnace, to test this point, detected only very minute retardations. I have now substituted a copper outer tube for the iron one.

TABLE 9.—*Loss of the Hardening Power. Influence of Quenching-temperature on Ductility of Quenched Metal.*

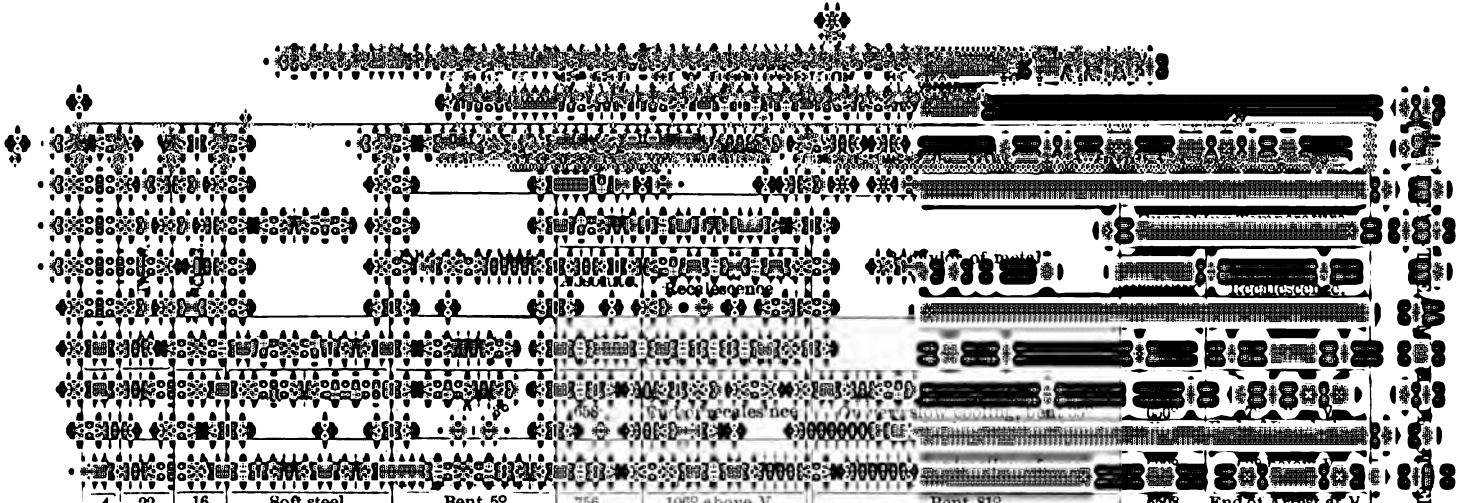
Bars quenched after partial slow cooling at normal rate.

Quenching-Temperature, degrees C., or in reference to V.			794° C.	772° C.	756° C.	704° C.	664° C.	655° C. Just above V.	Beginning of recalescence	Crest of recalescence	Crest of recalescence	End of recalescence	7° Below V.	642° C. 9° Below V.	605° C.
Series	Table	Grade.													
10	20	Hard tool-steel.	.....	0°	.....	.....	.....	.....	.....	(684° C) 0° a	(675°C) 2° b	(667°C) 5°	.....	.....	58°
9	19	Soft tool-steel.	.....	.....	.....	.....	.....	.....	(661° C.) 0°	.....	.....	(658°C) 3°	(650° C.) 35°	.....	.....
16	22	Soft steel { Bend.....	9°	.....	5°	18°	26°	55° c	.....	.....	.....	(650°) 81° c	.....	190°+	.....
		Soft steel { Color-carbon...	.124 p.c.	.....	.128 p.c.	.124 p.c.	.13 p.c.	.16 per ct.	.....	.....	.....	.22 pr.ct.	.....	.22 per ct.	.....

NOTE TO TABLE 9.—[a] Bar 108 was quenched at 684° C., at the crest of the recalescence, 6 seconds after reaching it.

[b] Bar 109 was quenched 42 seconds after reaching the crest of the recalescence (677° C.), and when the temperature had re-descended 2° C. from the crest, to 675° C.

[c] For the soft steel there is no true recalescence, but simply an arrest at V.



4	22	16	Soft steel.	Bent 5°	756	106° above V.	Bent 81°.	650°	End of Arrest at V.
				" 18	704	54 " V.	Bent double, 190° +.	642°	9° below V.
5	23	15	Soft basic steel.	.....	Any Temperature above W, strengthens and lessens ductility.			...	

not stay long enough at each degree of temperature to reach the maximum toughness attainable at that degree, *i.e.*, to permit this V-change to proceed as far as it can at that given degree.

Thus Table 19 shows that, when the soft tool-steel of Series 9 was quenched after staying for ten minutes at 1° below V (after the end of the recalescence), it was not only very much tougher than when quenched immediately after cooling moderately slowly to practically the same point relatively to V, bending 37° in the former against only 3° in the latter case; but even slightly tougher than when quenched after slow cooling to 7° below V. In this last case it took sixty-four seconds to cool through these last 7°.

Like results are given in Table 17, and recondensed in Table 11; but they are less conclusive, because the V-point was not noted.

TABLE 11.—*Influence of Time on Progress of V-change.*

SERIES 8. Rail Steel.

Bar.	P.	Heat-Treatment, heated to T, cooled slowly partly, quenched.			Permanent Bend.		
		Heated to	T, temperature to which cooled slowly before quenching.	Length of time held at T before quenching.	Bars quenched immediately after reaching T.		Bars held at T before quenching.
					Cooled at normal rate to T.	Cooled unusually slowly to T.	
51	133	722	700° C.	5 mins.	.....	.....	54°
40	88	726	678° C.	0	7°	.....	.....
53	134	722	"	0	20°	.....	.....
49	131	722	"	0	8°	.....	.....
50	132	722	"	30 mins.	.....	.....	189°
48	130	722	657° C.	0	18°	.....	.....
41	89	722	"	0	.....	117°	.....
55	136	736	"	3 mins.	.....	.....	197°
47	129	724	635° C.	0	93°	.....	.....
39	87	722	"	0	.....	193°	.....
56	139	736	"	5 mins.	.....	.....	192°

Here, simply by retarding the rate of cooling, the permanent bend of metal quenched immediately after cooling to 657° C. is increased from 18° to 117°, and that of metal quenched immediately on cooling to 635° is increased from 93° to 193°. Further, bar 50,

held at 678° for 30 minutes before quenching, bent double, and was thus very much tougher even than bar 41 cooled slowly 21° lower to 657°, and much tougher than bar 47, which was cooled 43° lower before quenching.

So bars 55 and 56, held 3 and 5 minutes respectively at their quenching-temperatures before immersion, were much tougher than the corresponding bars 48 and 47, quenched from the same temperatures without being thus held there.

But, while we thus see that time plays a *rôle* second only to that of temperature in the loss of the hardening-power, we have not yet touched the questions raised in (23). We do not know how far it is possible for the loss of the hardening-power to go at any given temperature, nor do we know whether it would become complete at V, and if not at V then at some point but slightly below V, if the metal were only held long enough there; or whether the V-change can complete itself only to a certain extent at V and just below it, so that the metal must cool considerably below V before this change can become complete.

It is not unlikely that, while the soft steels can lose a very considerable proportion of their hardening-power far above V and even above W, a proportion which increases as the temperature descends towards V, the hard steels can lose none of theirs till the temperature falls very nearly to V.

(40) *Hardening-Power Gained at W.*—Let us next study the effects of the W-change by noting the ductility of bars quenched from W and from neighboring temperatures. The results condensed in Table 12 indicate that the change at W is accompanied by a great loss of ductility; for, although the permanent bend decreases in general as the quenching-temperature rises, yet this decrease is extremely marked as we pass W.

The results in group II. of Table 26, for hard tool-steel, indicate that the acquisition of the hardening-power on quenching is due to the temperature, not as such, but as the cause of some change—the W-change—in the metal itself. For whereas, on the one hand, both here and in Table 12, the ductility decreases progressively as the quenching-temperature rises, provided that this temperature be at or above W; yet, on the other hand, if it be below W, the ductility bears no clear relation to the quenching-temperature. I believe that the following explanation suffices. As we shall see, the temperature to which this hard steel has been exposed affects its properties profoundly, even if the exposure be followed by slow cooling. So does

8	17	Rail.	.....	.....	.....	180°+ 4 cases.	107° av. 6 cases.	.....										26°, av. 6 cases		5°	2°	1°	
14	21	Rail.	.....	.....	.....	.....	.....	.....	.....	160°	105°	49°	.....	18°	.....	15°	14°	.....	12°	.....	.....	.....	.....
16	22	Soft Steel { Qu'nch'd in	brine	.....	.....	.....	197°[a]	.....	.....	.....	.....	.....	.....	36°	.....	.....	.....	.....	.....	.....	.....	5°	5°
			water	.....	.....	.....	.....	.....	.....	.....	.....	.....	199°[a]	.....	.....	192°[b]	.....	.....	.....	.....	.....	.....	66°

[a] Bent double without cracking.

[b] Bent double, but cracked deeply.

the cool rolling which the metal receives in the rolling-mill. One or perhaps both these influences, which are not fully effaced by thus heating to points below W, affect the ductility far more than the quenching from below W does, even though this quenching be from a fair red heat.

The bars of this steel which received no preliminary heating to above W are placed together in column A of Table 26; those in columns B to E inclusive were preheated and cooled slowly in order to remove the effects of previous cool-rolling. The bars of group II., column A, are much less ductile than most of those in the other columns when quenched from below W.

Bnt even slight variations in the quenching-temperature, once it closely nears or passes W, influence the ductility of the quenched metal to an astonishing extent. Thus, the permanent bend of one of the hard tool-steels (Series 10) falls from 50° to 4° on raising the quenching-temperature 5° C.; that of the other (Series 18) falls from 108° to 5° on raising the quenching-temperature about 5°; that of the soft tool-steel (Series 9) falls from 85° to 12° and then to 0° on raising the quenching-temperature first by 10° C., then by 5° more (relatively to W); that of the rail-steel (Series 14) falls from 160° to 49° and then to 6° on raising the quenching-temperature first by 5° and then by 12° more; that of the rail-steel (Series 8) is greatly and suddenly lowered; and even that of the soft steel (Series 16) falls from 197° to 36° on raising the quenching-temperature by 13°. I here tabulate these losses:

	On raising the quenching temperature (relatively to W) by	The Permanent Bend Fell	
		from	to
Series 10, hard tool-steel,—Table 20	5° C., then 2° C.,	50°	4°, then 1°
Series 18, hard tool-steel,—Table 26	5° C.,	108°	5°.
Series 9, soft tool-steel,—Table 19	10° C., then 5° C.,	85°	12°, then 0°
Series 14, rail-steel,—Table 21	5° C., then 12° C.,	160°	49°, then 6°
Series 16, soft steel,—Table 22	13° C.,	197°	36°

(41) *Series* 14.—The most complete set is that of the rail-steel of Series 14, Tables 12 and 21, which shows in eight successive stages an unbroken loss of ductility, from which we infer a continuous in-

crease of the hardening-power, as the quenching-temperature rises from just below W (711° C.) to 730° C.

(42) *Series* 10.—We have seen in (16) that W^a, in case of the hard tool-steel of Series 10, lies between W—6° and W—10°. In fair accordance with this is the fact that while bar 25, quenched at about W—7° or W—8°, had not gained the hardening-power measurably, *i.e.*, it was as ductile as those quenched from lower temperatures, and even more ductile than many of the bars of this same steel which had been cooled slowly completely, yet bar 26, quenched from a temperature only 2° higher, bent considerably less, 50° against 60°; and a further rise of the quenching-temperature by only 5°, probably past W, practically destroyed the remaining very considerable ductility, reducing the permanent bend from 50° to 4°. These bars were held for about five minutes at their respective quenching-temperatures.

Bar 106 of this series was quenched five seconds after the temperature had reached W. According to our earlier observations, from 14 to 40 per cent. of the total retardation should have occurred before reaching W; and therefore, if the acquisition of the hardening-power be proportional to the retardation, this bar should have gained rather more than this proportion of its total hardening-power, and according to equation [1] should be at least as much hardened as steel of $14 \times \frac{1.20}{100} = 0.17$ per cent. of carbon, and perhaps as much as steel of $40 \times \frac{1.20}{100} = 0.48$ per cent. of carbon is when fully hardened. Its bend of 34° indicates that the amount of hardening which had occurred is nearer the lower of the above limits. I believe that steel of 0.17 per cent. of carbon should bend not far from 34° when quenched from above W^b. A direct experiment is needed to establish this.

The record of the heating of this particular specimen shows that but little retardation occurred before reaching W. At the rate of heating here employed, the retardation at W is normally about 100 seconds; hence the slight hardening which this particular bar underwent agrees fairly with the slight amount of retardation which had actually occurred before quenching.

(43) *Ductility Lost More Suddenly by High-Carbon than by Low-Carbon Steels.*—As the quenching-temperature rises past W, the harder steels lose their ductility more suddenly than the softer ones. In other words, thus measured, the acquisition of the hardening

power is more gradual in case of the soft steels than in case of the harder steels. Table 12 shows us that while the hard tool-steels, Series 10 and 18, leap in a few degrees from great ductility to great brittleness, the hardening-power is gained more gradually and progressively by the rail-steel of Series 14.

Here two suppositions suggest themselves: (1) That the change which causes this loss of ductility, whatever be its nature, takes place more suddenly in the hard than in the soft steels; (2) that, if this change be a change in the condition of carbon, a transfer of part, say of one-half of the carbon of a high-carbon steel, to the hardening state, suffices to remove all the ductility, so that a further transfer of the last half of the carbon at a higher temperature to the hardening state causes no effect which a bending test detects. But the change of the last half of the carbon to the hardening state should affect the ductility of a low-carbon steel greatly. Indeed, both these suppositions are probably true. The heating curves (Figs. 1 to 8) support the former supposition. The hard tool-steel (Fig. 1) has a single very sharp retardation at W; in the soft steel (Fig. 5) the retardation is further spread out, and is seen to continue for at least 100° C. above the crest of W, and, indeed, to grow more marked at a point far above W; while in the very soft basic steel a second and probably a third retardation occur.

(44) *Position of W Probably Constant.*—I remark in passing that the great critical point in heating, W, seems to occur at practically the same temperature in all steels. The variations which have appeared are hardly more than we can readily explain by certain instrumental errors which I may discuss hereafter. In short, the marked hardening-point of all steels seems to lie nearly if not quite at the same temperature; but a further elevation of the quenching-temperature affects the soft steels very much more than the hard ones. Yet I think it probable that, between the limits of perhaps 0.80 per cent. and 2 per cent. of carbon, exactly the same temperature suffices and is necessary for hardening all true carbon steels. I know that this is contrary to tradition, and I give it simply as a conclusion towards which the present data point. Naturally, a needlessly high temperature, which would crack a very hard tool-steel, can be tolerated in case of a softer one.

Be it remembered that the W of Series 10 varied strangely in the abnormal cases in which T^{min} was not below V.

Should we find by further observations that W is as constant as it now appears to be, it would be a most convenient point for calibrat-

One might suppose that the reason why the bars quenched after heating up to 707° were much less hardened than those quenched after cooling to even lower temperatures, was that in the former the acquisition and in the latter the loss of the hardening-power had not sufficient time to proceed to the extent corresponding to the temperature reached.

Indeed, it is readily conceivable that if each had been held longer at its quenching-temperature before immersion, the difference in ductility might have been somewhat less; yet I think it most unlikely, at least in case of the harder steels, that this difference can be eliminated or even very greatly diminished in this way. It is most improbable that a longer exposure to 707°, the temperature up to which the high-carbon tool-steel of Series 10 had been heated before quenching, would have caused hardening and thus lessened the ductility; for this particular bar which bent 60° was held for five minutes at 707° before quenching, and yet when quenched was more ductile than those quenched from a lower temperature. Indeed, as the quenching-temperature rose successively from 667° to 707°, the ductility progressively increased. I here summarize.

Bar.	21	22 and 103.	25	26
Quenching-temperature,	667°	700°	707°	709°
Permanent bend of quenched metal,	50°	55° and 59°	60°	50°

With a slight farther rise of the quenching-temperature to 709° the ductility again decreases. This suggests that between 667° and 707°, instead of acquiring the hardening-power, the metal was annealing; but that W^a lies between 707° and 709°, so that here the metal begins to acquire the hardening-power. This is not surprising, for W lies only slightly higher, between 714° and 717°.

To clinch this, I quenched two bars of Series 18, hard tool-steel, after holding them at one and the same temperature, 700° C. (about 19° below W, and about 30° above V) for several minutes, one after simply heating it to 700° C. from the cold, the other after cooling it to 700° C. from 880° C., which is far above W. When quenched, the former was at least as soft as if it had been roughly annealed; the latter was dead hard. This, then, seems a neutral zone,—the hardening power seems neither to be lost nor acquired in

it. I here summarize these results in Table 14, giving with them the bends of two bars of the same lot just as received from the rolling-mill, and of two others which had been cooled slowly from 837° C. (1539° F.) in the tube-muffle, and would therefore usually be called annealed.

TABLE 14.—*Existence of a Neutral Zone.*

SERIES 18. Hard Tool-steel.

Bar.	Laboratory page.	TREATMENT.	Bend.
52	370	Heated slowly to 700° C., held there 7 minutes, then quenched in cold water.	55°
27	368	Heated to 880° C., cooled slowly to 700° C., held there 8 minutes, then quenched in cold water.	0
96	345	Bars as received from rolling mill, and not treated by heat at all.	37
28	345		37
50	369	Heated to 837° C., and cooled slowly in tube-muffle to the common temperature.	45
51	369		45
13	341	Heated slowly to 678° C., held there 9 minutes, then quenched.	58
19	366	Heated to 880° C., cooled slowly to 678° C., held there 8 minutes, then quenched.	43

(47) *Analogies.*—The fact that, in case of the harder steels, the W-change, including the acquisition of the hardening-power, does not occur till the metal has been heated to a temperature considerably above that at which the V-change occurs with its loss of the hardening-power, reminds us of the fact that the points at which freezing and melting set in do not necessarily coincide. Under favorable conditions water may be cooled considerably below 0° C. (32° F.) without freezing, and this phenomenon is much more marked in case of some other substances; that is to say, there seems to be a certain inertia or reluctance on the part of the substance to pass from the liquid condition to the solid. To those chemists who regard freezing and melting as essentially chemical changes from one allotropic or isomeric state to another, the resemblance is particularly striking. Such a substance can be cooled somewhat below the freezing-point without freezing, but if it be once frozen by further cooling and reheated to this same temperature just below the freezing-point, it does not melt again even in part. So while hard tool-steel does not lose its hardening-power when cooled to 700° C., even though it be held there, yet if it once be deprived of the hardening-power by further cooling, it will not regain it, nor apparently will it even begin to regain it, on reheating to 700° C., nor even on long

exposure to that temperature. There seems to be this difference, however, in case of the freezing or melting of water or other simple substance: If the temperature is low enough to permit any freezing, the whole will freeze; if it be high enough to permit any melting, the whole will melt if we allow sufficient time; but, at least in case of the soft steels, this does not seem to be the case with the W-change and the V-change.

There is the further difference that, whereas when pure water thus overcooled begins freezing, the heat evolved raises the temperature to a fixed and absolute maximum-point, the true freezing-point, 0° C. (32° F.), at which freezing now completes itself; in the case of steel the crest of the recalescence (the maximum point to which the heat evolved in the V-change raises the temperature) shifts with the position of V.

In both these respects, however, the behavior of saline solutions resembles that of steel. If such a solution be over-cooled, so that its water does not begin freezing till the temperature has fallen below its normal freezing-point, the maximum-point to which the heat now evolved raises the temperature is not fixed, but shifts with the degree of over-cooling which occurred before freezing began, and is in general the lower the greater the amount of over-cooling. Further, part only of the water actually freezes at this maximum-point, and in order to freeze the remainder we must again depress the temperature below this point. As we lower it thence progressively, more and more of this remainder freezes.

Here we have a striking resemblance to the varying position of V, and of the crest of the recalescence, which, as we have seen, shifts with V; and, further, a resemblance to the gradual progress of the V-change as the temperature sinks from V to V^b.

(48) *The limits of this neutral zone,* in which hard tool-steel will neither acquire much of the hardening-power if it be not previously acquired nor lose much if it has been acquired, remain to be determined. It extends neither to W nor to V, for we have noticed that bars quenched when heated nearly, but not quite, to W were somewhat hardened, and that those quenched when cooled to points somewhat above V were somewhat softened; and Table 7 shows us that when this steel is heated nearly, but not quite, to W, there was a slight retardation on again cooling past V, and that if we cooled it nearly, but not quite, to V, there was a slight retardation on again heating past W. So bars 13 and 19, of Series 18, Tables 14 and 26, were treated in the same way as bars 52 and 27, except

that they were held at a point 22° lower, viz., at 678° instead of 700° C. Bar 19 took a permanent bend of 43°; if quenched from 700° it should have taken no permanent bend, as the behavior of bar 27 shows. Hence it apparently lost much of its hardening-power between 700° and 678°; hence the neutral zone did not reach down to 678°.

It is too early to insist that this zone is absolutely neutral, for bar 27 may have undergone part of the V-change, yet not enough to give it any measurable ductility. For instance, if we assume that the changed condition of carbon causes the loss and acquisition of the hardening-power at V and W, then in bar 27 part of the carbon may have passed back from the hardening to the non-hardening state; yet enough may have remained in the hardening state to prevent the bar from taking any measurable permanent set on rupture. As to this, I hope to report later.

(49) *Résumé of Experiments on the Loss and Gain of the Hardening-Power, and on the W- and V-Changes.*—It thus appears that the V-change and the W-change are simply the opposite phases of the same transformation, the W-change conferring the hardening-power, the V-change removing it. The hardening-power is gained rapidly during the retardation at W, and is rapidly lost during the retardation at V.

The marked retardation which occurs at W, and which shows that some deep-seated change is occurring, does not take place unless the metal, since last rising past W, has been cooled so far as to induce the V-change. Nor does the well-marked retardation or even recalescence at V occur unless the metal, since last cooling below V, has meanwhile been heated highly enough to induce the W-change.

Further, so far as our experiments go, the amount of retardation in either phase (heating or cooling) is proportional to the amount which, by controlling the temperature reached in the opposite phase, we have permitted to occur in that opposite phase.

Neither change is instantaneous. The absorption of heat in rising past W, like the evolution of heat in cooling past V, occupies an appreciable time; and during this time the hardening-power is progressively acquired in one case and progressively lost in the other. So, part of the hardening-power is gained before the temperature has risen quite to W, *i.e.*, between W^a and W, and part of it is lost before the temperature has sunk quite to V, *i.e.*, between V^a and V.

The acquisition and loss of the hardening-powers seem to go on *pari passu* with the retardations. We have noted only two sug-

gestions of discrepancy in this respect, that the loss of the hardening-power seems to lag behind the V-retardation, and in case of the softer steels which have noticeable upper retardations, it seems to be if anything unduly concentrated into the V-range, and disproportionately small in the ranges where those upper retardations occur.

The distribution of the V- and W-retardations varies considerably, and after unknown laws. The positions of V and of W^b vary considerably; that of V^b probably more: but there is much to suggest that those of W, W^a and V^a are nearly and perhaps quite fixed.

W is not far from 713° C. (1315° F.). In case of the hard tool-steel of Series 10, W^a lay near 706° C., and V^a near 679° C. There was thus a range of some 27° C. (49° F.) between W^a where the W-change begins in heating and V^b where the V-change begins in cooling. Here W^b normally lies near 723°, and V^b between 645° and 674°; the W-range covers from about 14° to about 20°, and the V-range from about 5° to about 34°; but further and lower retardations may be related to it.

This range between W^a and V^a seems to be relatively and possibly completely neutral, at least for high-carbon steels: that is to say, high-carbon steel which by heating above W has acquired the hardening-power, apparently will not lose it in this range, nor can much of it here be acquired by high-carbon steel which has lost it by previous cooling to below V. In other words, steel quenched in this range will be hardened thereby if it has just previously been above W; but it will not be hardened thereby if it has just previously been below V.

IV.—Note on Osmond's Theory.

(50) *Note on Osmond's Theory.*—He holds that sudden cooling hardens steel, not as has been believed by retaining its carbon in a special hardness-giving condition, but by retaining the iron itself in a purely hypothetical special hard allotropic state of β-iron.

Let us glance roughly over the field. It was known that quenching made steel hard and brittle; that slow cooling made it soft and ductile; that the degree of hardening caused by sudden cooling was roughly proportional to the percentage of combined carbon in the steel; that the carbon in quenched steel was combined with the iron in a condition radically different from that of its combination with iron in slowly cooled steel; and that the passage of carbon from the state in which it exists in quenched steel (called the "hardening"

state) to that in which it exists in slowly cooled steel (called the cement state) occupied a very appreciable length of time, at least under certain conditions.

All of these facts, except perhaps the last, were beyond dispute. In view of the fact that carbon passes spontaneously to the hardening state as the temperature rises through redness, and spontaneously but not instantaneously back to the cement state as the temperature sinks past redness, it was reasonably inferred that the reason why quenched steel was hard was that the quenching offered insufficient time for the carbon to pass from the hardening to the cement state.

It was further known that, as the temperature of steel rich in carbon sinks below redness, its fall arrests itself suddenly and spontaneously, the metal grows visibly hotter, and then again cools off completely; and further, that this recalescence takes place only in steel containing much carbon, and that if the steel be quenched when far above this recalescence-point it becomes glass-hard, but not if it be quenched from far below this point. It was reasonably inferred that this recalescence was due to evolution of heat accompanying the passage of the iron and carbon from their hardening to their non-hardening state of combination.

This Osmond practically admits, holding that it is well established that the recalescence is due chiefly to a change in the relations between iron and carbon, and referring it to the heat which their combination evolves.*

Then Osmond found that, during the slow cooling of steels poor in carbon, there were several distinct retardations, such as Figs. 6, 7, and 8 show; one of them at about the temperature of the recalescence of steel rich in carbon, the others at higher temperatures. Each retardation was, of course, due to some change which evolved heat. Were they all due to the same kind of change? Osmond assumed that they were not. Two explanations suggest themselves. The first is that the upper and lower retardations represent successive fractions or instalments of a single change. This change might be composite in its nature, yet its components might accompany each other in more or less constant proportions in the different retardations, just as when we turn the slats more and more we cut off equally the different components of white light.

The second is that the upper retardations are due to a change essentially different from that which causes the lower. M. Osmond

* *Transformations du Fer et du Carbone*, pp. 13 and 28.

chose the latter explanation. His view seems to be that the single retardation of the hard steels at V is due to a group of changes which, though in essence distinct, here occur simultaneously.

These changes are (1) that of the carbon from its hardening to its cement state, and (2) that of the iron from the hypothetical β- to the α - state. In the soft steels these changes, he believes, occur separately, causing the different retardations, of which the upper ones are due to the β— α change, the lower to the carbon-change.

This assumed, the question remains: "Is quenched steel hard because sudden cooling denies time for the known change of carbon from the hardening to the cement state, or, because it denies time for the change from β- to α - iron?" M. Osmond chooses the latter supposition.

He reconciles this with the fact that the hardening-power is roughly proportional to the percentage of carbon in the steel, by supposing that the presence of carbon clogs or retards the change from β- to α - iron. He supposes that this change occurs nearly instantaneously if carbon be absent; hence, the softness of low-carbon steel even after sudden cooling. The change, he further supposes, takes place more and more slowly the more carbon the steel contains.

(51) *Test of his Theory.*—Admitting for argument's sake half of Osmond's theory, let us test by it the other half; *i.e.*, admitting for this purpose that the upper retardations in cooling represent the passage from β- to α - iron, and the V-retardation the change from hardening to cement carbon, let us directly test his theory by ascertaining to what degree the hardening-power is lost as the steel, cooling slowly, undergoes each of these successive retardations. To do this we have but to quench, at different points in the range which includes these retardations, a series of pieces of this soft steel which, by heating to above W, have acquired this hardening-power; and then to ascertain how much each is hardened. This test we have already applied to the soft steel of Series 15 and 16; and we have seen that the loss of the hardening-power, far from being confined chiefly to the upper retardation-points as Osmond's theory requires, is, if anything, disproportionately small there, and unduly concentrated into the lower or V-range. The evidence which I have offered on this point is thus directly opposed to Osmond's theory in its present form. I propose to apply still more accurate tests shortly.

It would have been well to apply this simple, direct and crucial test rigorously before publishing this theory, which now strikes me as untenable. How often does the investigator greatly reduce the

debt which the practitioner owes him for his investigations, by pubishing prematurely theories which, by their number and instability, confuse the beneficiary.

(52) *Test by Color-Carbon.*—Not content with this, I next sought an answer to the question: "If I quench a set of pieces of this soft steel of Series 16, which has these several retardation points, quenching each piece from a temperature a little below that at which I quench its neighbor, and if I thus obtain a series of quenched pieces, each less brittle and more ductile than its preceding neighbor, will the condition of the carbon in the quenched pieces correspond to their hardness, and like it to their quenching-temperature? *I.e.*, as the quenching-temperature descends, does the percentage of hardening-carbon progressively diminish and that of cement-carbon progressively increase in harmony with the progressively increasing ductility, slowly as we pass the upper retardation points, quickly as we pass V?

Closely pressed for time, I could do no more than determine the "color-carbon," by the Eggertz method, in the soft steel of Series 16, Table 22. I condense and rearrange the results in Tables 15 and 16. The Eggertz method cannot, I believe, be expected to give quite harmonious results. It simply indicates in a rough way the proportion of cement-carbon present, because part of the hardening-carbon is volatilized by the attack of the acid.

Arranging the cases in Table 15 in the order of temperature, we find very striking anomalies, a bend of 192° with a quenching-temperature of 732°, and bends less than 27° with temperatures from 664° to 704°. These anomalies nearly disappear if we take the condition of carbon into account; for the abnormally ductile bars have an abnormally high proportion of cement-carbon, because they were quenched in water instead of brine. But if we group these cases according to the carbon-condition, we find in Table 16 that, as far as the results go, the ductility agrees roughly with the proportion of cement-carbon, and that both increase markedly and simultaneously as the quenching-temperature sinks past V.

Moreover, in group IV. of Table 22, the change in the carbon-condition, like that in ductility, is, "if anything, unduly concentrated into the V-range and disproportionately small in the ranges where the upper retardations occur." Indeed most of each change occurs between 664° C. and 642° or 650°, which, as Fig. 6 shows, is just about the range covered by the V-retardation.

It is not to be supposed that the condition of carbon, if, as I be-

TABLE 15.—*Relation of Quenching-Temperature to Ductility and "Color-carbon."*

SERIES 16. Soft Steel.

Quenching temp., °C.		880°	803°	794°	756°	732°	726°	704°	664°	655°	650°	642°
Treatment.		Bend at Rupture and "Color-Carbon."										
Quenched in brine after heating.....	Bend.....	5°	5°	.....	.....	.....	36°	.....	.....	.....	.....	.....
	"Color-Carbon," %....	.124	.13	.....	.....	.....	.16	.....	.....	.....	.....	.....
Quenched in water after heating.....	Bend.....	66°	.....	.....	.....	192°	.....	.....	.....	.....	.....	.....
	"Color-Carbon," %....	.124	.....	.....	.....	.18	.....	.....	.....	.....	.....	.....
Quenched in brine after part'l cool'g	Bend.....	.....	.....	9°	5°	.....	.....	18°	26°	55°	81°	190°
	"Color-Carbon," %....	.....	.....	.124	.128	.....	.....	.124	.13	.16	.22	.22

TABLE 16.—*Relation of "Color-carbon" to Ductility.*

SERIES 16. Soft Steel.

Color-carbon, %...	0.124	0.128	0.130	0.160	0.180	0.210	0.220	0.220
Treatment.	Bends at Rupture.							
Quench'd in brine after heating.....	5°	.....	5°	36°	.....	.....	.....	.....
Quench'd in water after heating.....	66°	.....	.....	.....	192°	199°	.....	.....
Quenched in brine after par. cooling.....	9° and 18°	5°	26°	55°	.....	.....	81°	190°
Quenching temperature relatively to V.....	.....	.....	.....	Just above V.	.....	.....	Near end of V retardation	9° below V.

lieve, it be the chief, is therefore the sole element which determines the hardness and ductility. I repeat that the effects of stress and structure cannot be ignored.

We see in (54) how the properties of steel appear to be affected by variations in the temperature from which slow cooling occurs; that varying this temperature by 28° C. reduces the bend on rupture from 166° to 130° (Table 20); that by varying it some 182° C. reduces the elongation from 32.81 per cent. to 12.50 per cent. (Table 18). Yet these variations in the temperature from which slow cooling takes place can hardly be expected to influence seriously either the proportion of hardening-carbon, or that of β-iron.

Even copper, which, in view of its low elastic limit and great

thermal conductivity, should be affected but slightly by stress caused by sudden cooling, is shown in Table 27 to be stronger and far more ductile after quenching than after slow cooling.

(53) *Apparent Discrepancy Between Carbon and Ductility*.—I must now call attention to a discrepancy between bars 6 and III. of Table 22. Their color-carbon is alike, but the latter, quenched from a lower temperature, is much more ductile than the former. Such a single case may be due to error: but, if true, it would mean that, in slow cooling, some ductility-giving change continues after the carbon has fully changed from hardening to cement, *i.e.*, that the restoration of ductility lags behind or at least continues after the carbon-change. This wholly unexpected phenomenon reminds us startlingly of another equally unexpected, which we saw in (36), that the loss of the hardening-power seemed to lag behind the V-retardation. Of this lagging I do not remember hearing before now the faintest suggestion. But if further experiments should verify it, and prove that, while part of the restoration of ductility accompanies, another part of it succeeds the carbon-change, is this second part a true loss of the hardening-power, or is it due to underlying changes like those which cause such enormous differences in the properties of slowly cooled steel, and which contain little suggestion of hardening? In other words, does any considerable loss of hardness proper, of resistance to abrasion, accompany that portion of the restoration of ductility which thus seems to occur after the end of the carbon-change?

Osmond is estopped from asserting that this apparent lagging is due to a change from β- to α-iron, because he has demonstrated to his own satisfaction that this change from β- to α-iron causes the *upper retardations*, not the lower: while this suspected change below V, which causes this apparent lagging, is one that, if it exists at all, seems to cause *no retardation* and occurs *below* V.

I do not think that we are yet justified in drawing strong inferences as to the nature of the changes which cause the upper retardations; and I deplore the haste and positiveness that have been shown in defining it and in declaring it freed from all hypothesis.

V.—Influence of Slow Cooling From Different High Temperatures.

(54) Results of cooling steel slowly from different high temperatures are given in Tables 18, 20, 23, 24, and 25, groups VII. and VIII.

w cooling was complete; in
ing the temperature, and after

Rail-steel.

inches long and $\frac{5}{16}$-inch square, of

Bar No.	Further Treatment.	Bending Test.
	.....	187°T.
	nched.....	0°
	"	1
	"	2
	"	5
	"	11
	"	53
	"	10
	"	11
	"	65
	"	5
	"	41
	"	40
	"	188T.
	"	116
	"	180T.
	"	76
	"	192T.
	"	184T.
	"	180T.
	"	180T.
	"	190T.
	"	187T.
	d 32 min. and quenched.....	62
	d 5′, quenched.....	54°
	nched.....	7
	"	20
	"	8
	d 30′, quenched.....	189
	nched.....	18
	d more slowly than No. 48, quenched...	117
	d 3′, quenched.....	197
	nched.....	93
	d more slowly than No. 47, quenched...	193
	d 5′, quenched.....	192

When hammered close, 45 and 50 cracked

Let us, as before, designate as T^{max} the temperature from which slow cooling begins, *i.e.*, the temperature which is reached in the heating which precedes our slow cooling.

In case of the hard tool-steel of Series 10 and of the soft tool-steel of Series 9, we get the greatest ductility when T^{max} is but little above W.

TABLE 18.—*Effect of Heat-treatment on Tensile Properties of Soft Tool-steel.*

SERIES 9. Bars $\frac{5}{16}$-inch square.

GROUP.	Bar No.	Lab. Page.	TREATMENT. Heated to	TREATMENT. Further Treatment.	TENSILE PROPERTIES. Tensile strength, Lbs. per sq. in.	Elongation. Per cent.	Elongation. In.	Contract'n of area. Per cent.
II. Heated and quenched.	51	276	693° C.	Quenched in cold water.	139,246	14.	2	28.
IV. Quenched after partial slow cooling,	45	230	851°	Quenched in cold water after cooling slowly to: Crest of recalescence, 655°	72,640	0	.....	0
	43	231	851	Beginning of decline of recalescence, 652	69,412	0	.....	0
	54	233	851	V, at end of recalescence. 640	90,531	0	.....	0.6
	40	273	722	69° Below V, 609	102,309	.....	.....	39.36
VII. Heated, cooled slowly completely.	53	232	966°	Cooled slowly completely.	121,549	.....	.....	18.70
	48	235	909	" " "	125,809	12.5	2	8.47
	57	229	851	" " "	126,431	.....	.....	7.07
	46	234	726	" " "	99,426	18.75	2	38.18
	44	272	727	" " "	97,992	32.81	2	52.96
VIII. Heated, cooled slowly to below V, reheated to W, cooled slowly.	42	226	851°	Cooled slowly to 521° C., reheated to 732°, cooled slowly completely,	100,380	25.	2	46.24
	52	226	851		100,382	25.	2	46.42
	47	227	851	Cooled slowly to 521° C., reheated to 746°, cooled slowly to 521°, reheated to 729°, cooled slowly completely,	96,961	25.	2	48.43
	55	227	851		98,100	25.	2	50.00

As we raise T^{max}, we progressively and rapidly lessen the ductility of the slowly-cooled metal; but, at least in case of Series 9, we appear to increase its tensile strength. The results are too few in number to permit strong inferences.

The loss of ductility thus caused by raising T^{max} from just above W to higher temperatures is, in case of both these steels, removed, and probably completely, by again heating to W and cooling slowly thence (group VIII., Tables 18 and 20).

It is not necessary that the metal be cooled completely before this

re-toughening heating to W begins. If metal has lost its toughness by heating far above W, we restore its toughness, probably completely (bars 117, 118, 120, of Table 20), by cooling it to below V, then reheating it to W, then cooling it slowly.

Thus heating to W has in some way a wonderful toughening effect, which is lessened if the temperature rise even very slightly above W.

TABLE 19.—*Series* 9, *Soft Tool-steel.*

Influence of Heat-treatment on Rolled-bars, 4 inches long and $\frac{1}{16}$-inch square, of Soft Tool-steel.

Group.	Bar No.	Laboratory page.	Treatment. Heated to C.	Heated to F.	Cooled slowly to C.	Cooled slowly to F.	Remarks.	Bending Test.
			Deg.	Deg.	Deg.	Deg.		
I. Natural State..	1	31	.....	.....	.....	.....	.....	85°
II. Heated and quenched.	45	329	723	1334	.....	.....	Quenched at 9° above W.....	0
	252	316	720	1328	.....	.....	Quenched at 4 above W.....	12
	253	317	710	1310	.....	.....	Quenched at 6 below W.....	85
	18	157	707	1304	.....	.....	.....	50
	19	274	693	1280	.....	.....	Quenched at 19° below W.....	90
IV. Quenched after partial slow cooling.	58	330	880	1616	650	1202	Cooled very slowly; quenched at 7° below V.	35
	251	315	809	1488	661	1222	Quenched at beginning of recalescence.....	0
	250	314	808	1486	658	1217	Cooled to 658° faster than No 58; Quenched at end of recalescence.	3
VI.—Heated, slowly cooled partly, temp. held const. for 10m., bar then quenched.	41	318	880	1616	664	1227	Held for 10m. at 1° below V...	37

GENERAL NOTE to Tables 17 to 23 (inclusive), and to Table 26.

Except when expressly asserted to the contrary, all quenchings were in cold water, at or slightly below the temperature of the room.

The bending tests were made in my private laboratory, between dies under a hand press on bars $\frac{1}{8}$ in. square and 4 in. long, not machined, and as they left the rolling-mill.

The tensile tests were made in the mechanical laboratory of the Massachusetts Institute of Technology, by Mr. Wm. Haskins, and through the kind permission of Professors Lanza and Miller.

A double heating to W probably further intensifies this effect. Thus bar 118 first had its ductility lessened by heating to 956°. It was then cooled below V, reheated above W, again cooled below V, heated above W a second time, and cooled slowly. It bent 170°, or even more than any of the bars the ductility of which had

[illegible] $\frac{5}{16}$-inch square, of

	Bending Test.
[illegible] ment.	
[illegible]	34°
[illegible]	34
[illegible]	0
[illegible]	1
[illegible]	3
[illegible] minutes at	4
[illegible] ture, then	50
[illegible]	60
[illegible]	59
[illegible]	55
[illegible]	50
[illegible] reaching it.....	8
[illegible] "	4
[illegible] then quenched ..	2
[illegible] " ..	41
[illegible] " ..	87
[illegible]	0
[illegible] scence (V)....	0
[illegible] "	2
[illegible] "	5
[illegible] elow V.....	58
[illegible] wly.	18
[illegible]	34
[illegible]	32
[illegible]	42
[illegible]	54
[illegible]	104
[illegible]	130
[illegible]	166
[illegible] °C. } And then cooled slowly.	65
[illegible] +14	130
[illegible]	110
[illegible]	40
[illegible] +30	77
[illegible] W.	105
[illegible] +39	125
[illegible] o 518 deg., re- [illegible] oled slowly to [illegible] 33 deg., cool-	170

TABLE 21.—*Series* 14. *Rolled Bars $\frac{5}{16}$-inch square of Rail Steel.*

Influence of Heat-treatment on Rolled-bars, 4 inches long and $\frac{5}{16}$-inch square.

	Bar No.	Laboratory page.	Treatment. Heated to °C.	Heated to Relatively to W.	Further.	Bend at Rupture.
I. Not treated.					As received from rolling mill.	180°+
II. Heated and Quen'd.	II.	320	730	W + 13°	Quenched.....	6°
	6	392	726	W + 13°	"	12°
	I.	319	727	W + 11°	"	14°
	5	390	720	W + 9°	"	15°
	10	394	714+	W + 4°	"	18°
	7	393	713	W + 1°	"	49°
	8	391	711	W	Quen. at W, 13 secs after reaching W	105°
	III.	321	711	W — 4 ±	Quenched at 4° below W	160°
IV. Quenched after partial slow cooling.	IV.	322	880		Cooled slowly to 615°C., and quenched.	78°

TABLE 22.—*Series* 16. *Soft Steel.*

Influence of Heat-treatment on Rolled Bars, 4 inches long and $\frac{5}{16}$-inch square, of Soft Steel.

Group.	Bar No.	Laboratory page.	Treatment. Heated to C.	Heated to F.	Cooled slowly to C.	Cooled slowly to F.	Position of quenching-temperature with reference to V and W.	Bend at rupture. Quenched. In brine.	Quenched. In water.	Carbon by Eggertz colorimetric method.
I. Not treated	.....	.....	Deg.	Deg.	Deg.	Deg.	.....	*180+	.....	.....
II. Heated and quenched.	9	332	880	1616	.....	.....	.....	5°	.....	.124
	14	325	808	1486	.....	.....	.....	5°	.....	.13
	13	328	726	1339	.....	.....	4° C. above W.....	36°	.....	.16
	10	337	707	1304	.....	.....	9° C. below W.....	197°	.....	.....
	11	331	880	1616	.....	.....	.....	.....	66°	.124
	8	324	732	1350	.....	.....	9° C. above W.....	.....	192	.18
	22	323	726	1339	.....	.....	3° C. above W.....	.....	199	.21
IV. Quenched after partial slow cooling.	II.	298	897	1647	794	1461	.....	9°	.....	.124
	5	301	880	1616	756	1393	.....	5°	.....	.128
	IIII	300	880	1616	704	1298	V + 54° ±.....	18°	.....	.124
	I.	297	880	1616	664	1227	.....	26°	.....	.13
	7	303	880	1616	655	1211	Quenched when just above V...	55°	.....	.16
	6	302	880	1616	650	1202	" at or near end of arrest at V.....	81°	.....	.22
	III.	299	880	1616	642	1188	" when 9° C. below V, probably about V°.	190°+	.....	.22

NOTE.—a. Bent double without cracking.
b. Bent double, but cracked very deeply.

TABLE 23.—*Effect of Heat-treatment on Tensile Properties of Soft Basic-steel.*

SERIES 15. Bars $\frac{5}{16}$-inch square.

GROUP.	Bar No.	Lab. Page	TREATMENT. Heated to C.	F.		TENSILE PROPERTIES. Tensile strength, lbs. per sq. in.	Elongation. Per cent.	In.	Contract'n of area. Per cent.
I. Heated and quenched.	60	385	984°	1803°	Quenched in freezing mixture...	63,317	14.06	2	53.85
	23	312	880	1616	Quenched in brine....	91,750	16.66	1	51.21
	31	312	882	1620	" " "	98,799	25.00	1	56.45
IV. Heated, cooled slowly partly, quenched in brine.	35	306	884°	1623°	Quenched in brine after slowly cooling to 822	97,438	.....	.....	45.24
	25	306	880	1616	822	90,319	15.64	2	51.69
	33	311	886	1627	765	100,705	14.06	2	38.07
	22	310	880	1616	706	99,096	21.87	1	37.65
	34	310	"	"	701	97,087	.....	.....	41.75
	32	309	"	"	664	98,931	.....	.....	39.24
	24	309	"	"	661	100,198	20.31	1	49.61
	27	308	881	1618	650	98,803	.....	.....	55.53
	26	305	880	1616	637	94,341	.....	.....	51.51
	30	305	"	"	629	69,179	15.62	3	62.12
	40	336	"	"	519	50,737	40.63	2	59.88
	41	336	"	"	521	52,451	39.06	2	55.78
VII. Heated, slowly cooled complet'y	21	307	1002	1836°	Cool'd ext'm'ly slowly completely	47,704	43.00	2	65.46
	29	311	886	1627	" " "	48 574	40.64	2	65.48
	28	308	881	1618	" " "	51,428	40.64	2	68.47
VIII. Thrice heated past W, with cooling past V.	36	333	.....	.....	Heated to 736° C., cooled slowly to 571,° reheated to 743°, cooled slowly to 578°, reheated to 736°, cooled slowly completely.	46,463	45.00	2	68.86
	37	333	.....	.....		46,449	45.00	2	67.85
	38	334	.....	.....	Heated to 736°, cooled slowly to 521°, reheated to 736° C., cooled slowly to 521° C., reheated to 742° C., cooled slowly completely.	45,000	43.74	2	58.82
	39	334	.....	.....		44,936	48.44	2	57.92

not been lessened by too high heating. Yet, if it had not been thus reheated, it should have bent only about 34°, judging from bar II.

I looked for some of these effects in the extra hard steel of Series 17 and in the soft steels of Series 15 and 16, but I failed to find them. If, as is probable, the steel of Series 17 was injured by heating it to 880°, this injury was not removed by reheating to a

TABLE 24.—*Effect of Heat-treatment on Tensile Properties of Soft Steel.*

SERIES 16. $\frac{5}{16}$-inch square rolled bars.

Group.	Bar	Lab. Page	Treatment. Heated to C.	Heated to F.	Position of W.	Further Treatment.	Tensile Properties. Tensile strength, lbs. per sq. in.	Elongation. Per cent.	Elongation. In.	Contract'n of area. Per cent.
IV.	43	384	880°	1616°	.....	Cooled slowly to 621° C., then quenc.	87,761	.....	.....	32.54
VII.	36	382	880	1616°	.....	Cooled slowly completely.	69,181	32.81	2	49.45
	41	389	737	1359	717°		68,727	35 93	2	54.54
	37	388	733	1352	717		68,416	34.37	2	51.13
VIII.	40	388	.....	.....	717	Heated to 733° C., cooled slowly to 346°, heated to 735°, cooled slowly to 418°, heated to 735°, cooled slowly completely.	66,968	29.64	2	52.94

NOTE.—Bar 37 had previously been heated to 880° C., and cooled slowly. Bar 41 had not been heated before the heating to 737° of this experiment.

TABLE 25.—*Effect of Heat-treatment on Tensile Properties of Extra Hard Tool-steel.*

SERIES 17. $\frac{5}{16}$-inch square rolled bars.

Group.	Bar No.	Lab. Page	Treatment. Heated to C.	Heated to F.	Position of W.	Further Treatment.	Tensile Properties. Tensile strength, lbs. per sq. in.	Elongation. Per cent.	Elongation. In.	Contract'n of area. Per cent.
VII.	2	381	880°	1616°	722°	Cooled slowly completely....	101,528	6.25	2	9.17
	3	381	"	"	722	" " "	98,417	.....	.....	3.95
	1	383	"	"	721	Cooled slowly to 450°, reheated to 732°, cooled slowly completely.	94,086	4.69	2	5.28
	8	383	"	"	721		91,017	.....	.....	6.47

little above W (bars 1 and 8, Table 25). The soft basic steel of Series 15 was as tough when cooled slowly from 1002° or 886° as when slowly cooled thrice from just above W (Table 23), whence I

TABLE 26.—*Series* 18.

Rolled-bars, $\frac{A}{16}$-inch square, Hard Tool-steel.

Group.	Bar No.	Laboratory page.	Treatment in this Experiment. Heated to C. Deg.	Heated to F. Deg.	Further Treatment.	Previous Treatment. A. None.	B. Heated to 738°C., cooled in air.	C. Heated to 788°C. and cool'd rather slowly.	D. Heated to 788°C., cooled slowly in furnace.	E. Heated to 817°C., cooled slowly in furnace.
						Bend at Rupture.				
I. Not treated.	96	345	.....	.....	.....	37°	.....	.....	.....	.....
	28	345	.....	.....	.....	37	.....	.....	.....	.....
II. Heated and Quenched.	29	353	740	1364	Quenched at W + 21°	.....	.....	0°	.....	.....
	24	355	723	1334	" at W + 4°	.....	.....	3	.....	.....
	10	354	719	1325	Quenched after staying 33 seconds at W	.....	.....	5	.....	.....
	3	356	714	1317	Quenched at about W — 6°	.....	.....	108	.....	.....
	15	346	714	1317	"	49	.....	.....	.....	.....
	7	344	709	1308	"	63	.....	.....	.....	.....
	25	359	707	1304	"	.....	.....	.....	81	.....
	22	363	707	1304	"	.....	.....	.....	77	.....
	1	343	701	1294	"	.....	62°	.....	.....	.....
	20	358	700	1292	"	.....	.....	.....	107	.....
	21	362	700	1292	"	.....	.....	.....	83	.....
	16	339	693	1280	"	47	.....	.....	.....	.....
	31	342	693	1280	"	.....	39°	.....	.....	.....
	14	351	693	1280	"	.....	130°	.....	.....	.....
	4	365	693	1280	"	.....	.....	.....	97	.....
	18	350	678	1252	"	.....	116	.....	.....	.....
	26	338	664	1227	"	36	.....	.....	.....	.....
	5	349	664	1227	"	.....	101	.....	.....	.....
	12	347	592	1098	"	.....	49°	.....	.....	.....
	17	364	592	1098	"	.....	.....	.....	127	.....
III. Heated, held and quench'd.	11	340	700	1292	Quenched after holding at constant temperature during 30 min.	65	.....	.....	.....	.....
	52	370	700	1292	Quenched after holding at constant temperature during 7 "	.....	.....	.....	.....	55°
	13	341	678	1252	Quenched after holding at constant temperature during 9 "	58	.....	.....	.....	.....
IV. Quenched after partial slowcooling.	27	368	880	1616	Cool'd slow to 700°C., held 8 min., qu'nch'd.	0	.....	.....	.....	.....
	19	366	880	1616	" 678°C., held 8 "	43	.....	.....	.....	.....
VII.—Heat'd, cooled slowly.	30	367	595	1103	Cooled slowly, completely.	.....	.....	.....	93°	.....
	53	371	595	1103	Cooled slowly, completely.	.....	.....	.....	47°	.....
VIII.	23	360	593	1100	Heated above W, cooled slowly completely, heated to 693°C., and quenched.	.....	.....	.....	170	.....
IX.	50	369	.....	.....	These were heated with 53 & 52 to 837°C., cooled slowly, and not farther treated.	.....	.....	.....	.....	45
	51	369	.....	.....		.....	.....	.....	.....	45

NOTE.—During this time the temperature of bar 11 varied between 693° and 704°.
That of bar 52, between 697° and 701°.
" 13, " 675 " 683.
" 27, " 697 " 701.
" 19, " 674 " 684.

TABLE 27.—*Effect of Heat-treatment on Tensile Properties of Copper.*

Round bars 0.37-inch in diameter.

GROUP.	Bar No.	Lab. Page	TREATMENT. Heated to C.	Heated to F.	Further Treatment.	TENSILE PROPERTIES. Tensile strength, Lbs. per sq. in.	Elongation. Per cent.	Elongation. In.	Contract'n of area. Per cent.
I.	1	.....	.....	.....	Untreated bar.....	37,161	37.50	2	56 51
II.	12	385	984°	1803°	Quenched in a freezing mixture, at — 7° C. (+ 19° F.)	29,506	43.75	2	39.10
VII.	2	387	973°	1783°	Cooled slowly completely...	26,948	25.00	2	23.61

infer that it is not injured by heating even to 1002°. The soft steel of Series 16, too, was practically as tough when cooled slowly from 880° as when cooled from 733°, just above W (Table 24), and cooling it slowly thrice from just above W gave no additional toughness.

We see, from Series 9 and 10, that variations, and sometimes slight ones, in the maximum temperature reached, *i.e.*, in that whence slow cooling starts, apparently have a wonderful effect on the properties of the metal. The cooling was in all cases so slow that we cannot refer these effects to stress, nor can we suppose that they are due to our not allowing sufficient time for the carbon to change from the hardening to the cement state, or for the iron to change from the β to the α state. Should further experiments corroborate this, we should clearly be in the presence of some cause of titanic power, a cause which neither the carbon theory nor the β—α theory of the hardening of steel takes into account. Should we hold either that hardening-carbon or that β-iron is the true cause of hardening, we should yet have to admit the existence of another influence, which, as an independent variable, powerfully affects the properties of the metal. Hence we could not expect to find a complete accord between those properties and the proportion of hardening carbon or of β-iron, as the case may be.

VI.—Description of the Tube-Muffle Furnace.

(55) This furnace is practically the common laboratory analytical gas-fired combustion-furnace, with its glass tube replaced by the iron and copper tubes, G and M, and surrounded with brick-work to lessen radiation and to give better control over the temperature.

The burners, J, are those of the common combustion-furnace.

The bar, K, to be heated is laid on another, L, cut from the same rod, and inside the copper tube, G. L rests on little strips of iron, to raise it above the bottom of G, so that both bars may be heated alike by radiation rather than by conduction.

The copper tube, G, rests within the wrought-iron tube, M, and is held concentrically with M by packing a little ring of asbestos between them at either end of G.

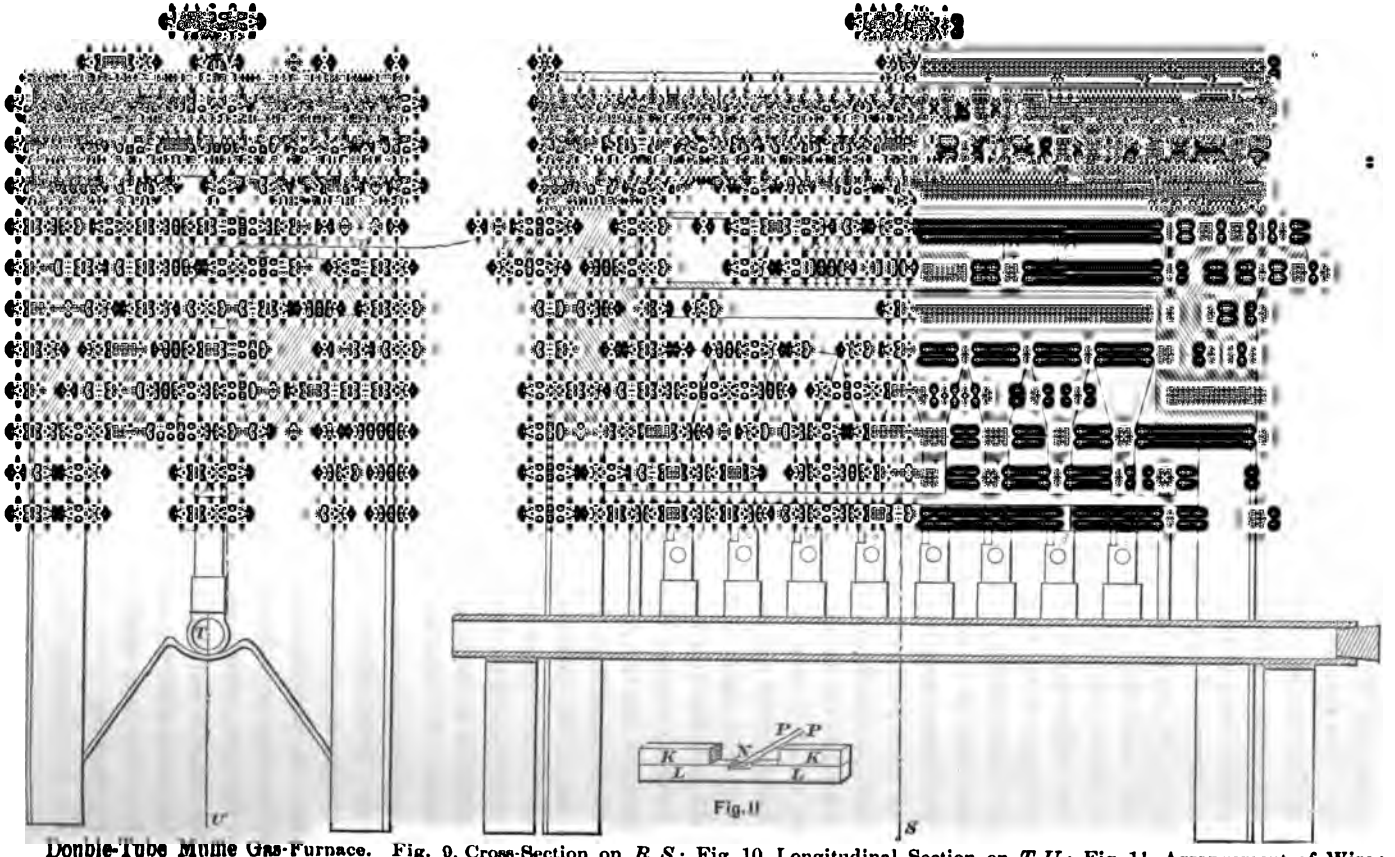
The thermo-electric junction, N, formed by the junction of a wire of pure platinum with one of platinum alloyed with about 10 per cent. of rhodium, lies between the bars K and L, in a little notch filed in the latter. The leading-in wires pass to the galvanometer, which is at a convenient distance from the furnace, through the double-bored clay tube, O.

My special object in designing this furnace was, first, to have the thermo-junction at a temperature very near that of the bar, K, under observation; to have this bar at a uniform temperature throughout; and to have this temperature completely under control.

(56) *Precautions.*—Unless special precautions are taken, the temperature of the thermo-junction may differ very considerably from that of the bar under treatment.

It does not suffice simply to lay the junction against the bar, unless the latter be at the same temperature as the surrounding atmosphere and walls. If it be not, then the junction will be at a temperature intermediate between that of the bar and that of the surrounding objects. It is difficult to have the bar and the surrounding objects at the same temperature, unless a muffle be used; and even with a muffle it is possible only when the temperature is stationary or at most moving very slowly. But by imbedding the junction between two like bars, which are under like conditions as regards heat, its temperature is but slightly affected by that of other objects. Nevertheless, even with the arrangement shown here, the influence of the walls of the inner muffle is not wholly effaced during rapid changes of temperature.

The galvanometer shows at any moment the temperature of the



Double-Tube Muffle Gas-Furnace. Fig. 9, Cross-Section on *R S;* Fig. 10, Longitudinal Section on *T U;* Fig. 11, Arrangement of Wire; *F*, clay-stoppers; *G*, copper tube or inner muffle; *J*, burners; *K*, bar to be heated; *L*, supporting bar of the same material as *K;* *M*, wrought-iron tube or outer muffle; *N*, thermo-electric junction; *O*, double-bored clay tube; *P*, wire leading to galvanometer; *Q*, sheet-iron diaphragm.

thermo-junction itself, unless the leading-in wires be short-circuited; if they are, the galvanometer shows their temperature at the point of short-circuiting. Now the leading-in wires, small though they be, are good conductors of heat, and with the very great differences of temperature which often exist between neighboring parts of apparatus for high-temperature experiments, they may conduct enough heat to the thermo-junction or away from it to affect its temperature seriously. For instance, it was actually found that, if the double-bored clay tube, O, was broken, so that the leading-in wires were exposed to the flame, they conducted so much heat to the thermo-junction that the readings of the galvanometer were much too high. On cutting off the gas the temperature of the couple would drop 4° or even 6° instantaneously, clearly because the wires, superheated by the naked flame, had been conducting heat to the thermo-junction, and raising its temperature above that of the bars which surrounded it, and so above the temperature which was under examination. After such a drop of 4° or so, the galvanometer took up the regular gradual movement due to the cooling of the bars. But when the wires were protected by the clay tube, no drop of this kind could be induced.

Apart from the influence of the exterior part of the leading-in wires, as the temperature of the apparatus rises or falls, the thermo-junction tends to outrun the bar of steel under treatment and observation, to be slightly hotter than the steel while the temperature is rising, and slightly cooler when it is falling. This, of course, because the steel must always lag behind the walls of the muffle, and lag behind them more than the leading-in wires do; as these outrun the steel, so, owing to the heat which they conduct to the thermo-junction, will it outrun the steel. Moreover, the outside of the steel bars will always slightly outrun their interior; and as the wires are very apt to short-circuit through the skin of the bars where they pass from between them, our readings on this account, too, tend to outrun the average temperature of the steel.

But even the thin walls of the clay tube, O, which surround the wires probably conduct heat rather more slowly than the double metallic walls of the muffle. This difference tends to make the wires lag where they pass through the tube, O, and thus tends to counteract their tendency to outrun the steel under treatment. As one error tends to counteract the other, the net error is probably very slight. I doubt if it can amount to more than a degree, at least when the temperature of the whole is changing at a moderate rate only. It

was observed repeatedly that, when the upper bar was withdrawn, leaving the thermo-junction exposed to direct radiation from the walls of the muffle, the reading of the galvanometer would vary very slightly; indeed, not at all, if the temperature had been changing only very slowly. If the more powerful radiation from the walls of the muffle thus substituted influenced the temperature of the thermo-junction so slightly, the much feebler influence of the leading-in wires, when the junction is protected by the bar under treatment, can be neglected in such a furnace as this, during slow changes of temperature.

Of course, when any such apparatus cools rapidly, the leading-in wires must outrun the bars operated on, and so must the thermo-junction, and through it the readings of the galvanometer. The faster the apparatus cools, the more will the readings of the galvanometer outrun that of the bars under treatment, and the more will their true temperature at any moment be above their temperature as reported by the galvanometer. The same thing applies, *mutatis mutandis*, to variations in the speed of heating.

I have dwelt on this at length, because it casts some doubt on a series of results obtained by M. Osmond. He found that increasing the rapidity of cooling lowered V, the recalescence point.

This would be a striking and important fact. But his apparatus was so arranged that the reported lowering of V may be due in part, if not wholly, to the source of error which I have just described. The apparent temperature of V would be that of the *thermo-junction* at the time when the *bar* itself was really at V. This apparent temperature would be below V, the more so the faster the cooling. Hastening the cooling would certainly cause an apparent depression of V, possibly even sufficient to explain the depression recorded by Osmond.

A fact which lends plausibility to this suspicion is the following: When he used small *square* bars he found that V was lowered by only some 29° by accelerating the cooling; but when he used still smaller *round* bars, V was lowered by some 90°. Clearly, the influence of the leading-in wires would be likely to be much greater in case of round than in that of square bars, for the latter hug the thermo-junction much better than the former do.

(57) *Evidences of Accuracy.*—An interesting phenomenon testifies that the temperature during very slow heatings and coolings was extremely uniform within the copper tube. When, during such a heating or cooling, the inner tube was opened, its contents were wholly

invisible for a few seconds, and then the nearer end of the two bars gradually appeared. This was true even at low redness, as well as at all higher temperatures, and evidently was in no way due to dazzling. As the contents of the tube were all at very closely the same temperature, so they all glowed with precisely the same intensity and tint, and the eye, which sees things solely by difference of tint or shade or brightness, simply saw uniform red or yellow light, and nothing more. After a few seconds the cool outer air, entering the tube, cooled the ends of the bars so far that their tint was slightly darker than that of the rest of their length and of the tube itself, and these ends became visible, while the rest of the bars and the interior of the muffle remained invisible.

Some of the tensile-tests of bars which had been treated agree very closely, and testify to the uniformity of heating. Such are the tests of bars 42 and 52 of Table 18; of bars 38 and 39, and 36 and 37 of Table 23.

Where bending-tests were made on bars which had been treated alike, or which had not been treated at all, the results agreed. See, for instance, the tests of bars 96 and 28 of table 26, both of which bent 37°; and bars 50 and 51 of the same table, both of which bent 45°.

The sharpness with which the retardations, and especially the recalescences, often begin, shows that the temperature, not only of the two bars as a whole, but also of the different parts of each bar, is approximately uniform; for any considerable irregularity in the temperature of the metal would make the recalescence begin gradually instead of abruptly. For instance, suppose that one end of the two bars was considerably hotter than the other, and that, at any given instant, there was a regular increase of temperature, as we passed from the cool towards the hot end. If, in this condition, the two bars are cooling towards V, different parts of them will successively reach V, and will successively recalesce; that is to say, the recalescence, instead of beginning simultaneously throughout the bars, will travel from the cool end towards the hot end, as one point after another cools as far as V. Under these conditions, the descent of the temperature of the thermo-electric junction, instead of continuing at full speed till V is quite reached and then abruptly changing to a rise of temperature, would necessarily slacken much and progressively before reaching V, because the recalescing of the adjoining parts, which reach V earlier, would gradually retard the cooling of this junction more and more as the recalescence, travelling

along the bars, drew nearer and nearer to the junction. Yet actually the recalescence begins very suddenly—often with hardly any warning. I give here the intervals (seconds per 1.4° C.) in the cooling near and at V, in a few cases:

2.5; 2.5; 2, 2; 4; 3; 5; 3; 2; 2; 2; **95**; 5; 5; 8.
2; 2; 3; 3; 4; 4; 4; 2; 3; 4.5; 4.5; **107**; 4; 3; 4; 4.
2; 2; 2; 2; 4; **118**; 5; 4; 4; 4.

But the converse does not follow. A gradual instead of an abrupt beginning of the recalescence would not argue that the temperature of the bars was not uniform, because the gradualness might be due to the very nature of the recalescence itself.

By like reasoning, an abrupt beginning of any retardation argues that the temperature is uniform throughout the bar treated.

The constancy of the apparent position of W and W^a, noted in (16), is further evidence that the conditions were uniform, and evidence, indeed, of the accuracy attainable under these conditions. Even if the true position of W and W^a be absolutely fixed, we should expect that errors of observation would cause the apparent position to vary. And it was to be feared that these errors would be considerable; for variations in the conditions of heating and cooling were introduced intentionally; and the considerably varying temperature of the room should affect the readings of the galvanometer, and together with varying draughts, and varying conduction of heat through the furnace walls, might alter the difference between the temperatures of the metal under observation and of the thermo-electric junction by which its temperature was observed. Indeed, the fact that in the eleven normal cases in which it was observed in Table 7, W^a varied by only 1.4° C., while in eight of those cases W varied by only 1.4° C., and in ten of them by only 2.8° C., argues that the net effect of these sources of error need not be serious.

The air-space between the iron and copper pipes tends to equalize the temperature of the latter; and copper was used for the inner muffle because it conducts heat so rapidly that the temperature of its different parts was very uniform.

The double sheet-iron diaphragms shown were designed to cut off radiation to and from the clay plugs at the outer ends of the iron tube.

It is not difficult to control matters so that the temperature of a bar, at the moment of its withdrawal from the furnace, shall not

vary more than 1.5° C. from the temperature aimed at; this demands only that the temperature shall vary slowly, and to ensure this requires no great care in design. But it is a far different and very difficult thing to hold the temperature stationary at a predetermined point. Yet, so good was the control over the furnace that its temperature has appeared absolutely constant for six minutes, during which it certainly did not vary more than 1.4° C. In another case the apparent variation was only 1.4° C. during a period of seven minutes.

DISCUSSIONS.

[NOTE.—The following discussions of papers contained in this volume are printed without regard to order of succession. It has been impracticable to secure from the various parties, corrected reports of their contributions in time to effect any particular desired arrangement in this respect.

The discussion here printed under the title "Physics of Steel," covers, besides papers contained in this volume, those of Messrs. Pourcel, Osmond and Sauveur, in vol xxii.]

THE LIMITATIONS OF THE GOLD STAMP-MILL.

Discussion of the Paper of Mr. T. A. Rickard. (See p. 137.)

R. RICKARD, Berkeley, California: I have been much interested in Mr. Rickard's description of the method of gold-milling now in use in Colorado.

There has always been a very wide difference of opinion regarding the merits of the Gilpin county method of dealing with the ores of that district. The present system of milling was introduced into Gilpin county at a time when there was no market for low-grade ores. Freights and smelting-charges were such that only the highest grade of ores was profitable to handle. Had the present condition of railroad facilities and ore-market been in existence, it is more than doubtful whether the system would have been so universally adopted. For the purpose of discussion, I would suggest whether a modification of the present system would not be advantageous.

In the early days of milling, and when there was no market for low-grade concentrates, the material flowing from the amalgamating-plates went direct to the creek; but later, when the large smelting industries of Denver opened a market for such by-products, concentration was resorted to with a very considerable increase in the yield of the ore.

In the paper under discussion, it is admitted that the gold and silver are chiefly contained in, and associated with, the pyrite; and the reason given for the high drop and consequent slow milling is the necessity of reducing the sulphides to a very great degree of fineness in order to liberate the precious metals for amalgamation.

In an article written by the same author and published in the *Engineering and Mining Journal* of September 10, 1892, the result of a careful test of milling 8400 pounds of ore from the California mine in the Hidden Treasure mill is given as follows:

	Gold, ounces.	Silver, ounces.
Contents of ore,	7.46	32.86
Yield:		
By amalgamation,	5.25	14.00
By concentrates,	1.74	10.22
	6.99	24.22

Equal to 93 per cent. of the gold and 73 per cent. of the silver contents of the ore treated.

It will be seen by these figures that slow work and fine crushing do not liberate all the gold and silver, as only 70 per cent. of the former and 42 per cent. of the latter are arrested by amalgamation, while 33 per cent. of the gold and 31 per cent. of the silver are still held by the pyrite, or such portion of it as is saved by concentration.

In view of the result shown by these statements, the question naturally arises whether it would not be advantageous to introduce concentration at an early stage of the operation, crushing coarser and faster, thereby avoiding the certain increased loss from excess of slimes due to fine crushing, placing the concentrating-tables at the outlet of the battery, and removing at this stage of the operation all of the pyrite and its gold and silver contents, before passing the remainder of the pulp over the amalgamating-tables.

In the article referred to, a comparison is made between milling and the treatment of the same ore by the smelter, with a result favorable to milling. The figures are as follows:

	Wet.	Dry.	
Ore treated,	8400 pounds.	8064 pounds.	
Obtained by milling, bullion,		$107.20	
Concentrates, net,		36.03	$143.23
Less milling, 84 cents per ton,			3 53
Net return by milling,			$139.70
If sold to the smelter the same ore would yield,			109.18
Leaving a balance in favor of milling of,			$30.52

If we take the same quantity of ore and treat it as suggested above, it will be found that the result will not show the present mode of milling in such a favorable light.

The contents of the ore are 7.46 ounces of gold and 32.86 ounces of silver.

The losses under the present system are probably greater than they would be if the ore were crushed coarser. For the purpose of the calculation, we will take the yield of gold at 93 per cent. and that of silver at 80 per cent. The original dry weight of 8064 pounds would be reduced by concentration to 2822 pounds, since 60 or 70 per cent. is the estimated proportion of soft feldspathic gangue in the ore, and this is easily removed.

2822 pounds yielding 6.83 ounces gold at $20 would give,		$136.60
and 26.28 ounces silver at $1, ...		26.28
		$162.88
Smelting-charges and freight, $8 per ton, . .	$11.29	
Milling, 30 cents per ton by the fast-drop mill of California type, ...	1.26	$12.55
Net return, ...		$150.33
Milling as at present, ...		139.70
In favor of proposed change, ...		$10.63

or $2.62 per dry ton or $2.53 per wet ton of ore treated.

The price of silver has been taken at $1 per ounce, because that is the value which figures in the article referred to.

It would be of great service to the mining industry if some of the mine-owners in Colorado would make a test on the proper scale and with such thoroughness of detail as would make the experiment trustworthy.

HENRY A. VEZIN, Denver, Colo. (communication to the Secretary): About 1873 a well-known metallurgist made some experiments in dressing ore from a mine in Gilpin county. It was done by a hand-jig and a tossing-kieve. No attempt was made to treat the refuse by amalgamation. The result was so favorable that he suggested to the manager of the mine the policy of crushing and jigging his ore, and allowing the tailings to go to the stamp-batteries, where all the ore was then being treated. Stamps were at that time the only available amalgamating-machinery; but the metallurgist referred to anticipated that in order to obtain the best results, the ore would have to be crushed by successive comminution so fine that the tailings could not be fed to stamps; and he therefore had in view the use of other machinery to prepare the tailings for amalgamation. However, for the purpose of the experiment they could go to the stamps, provided coarse material was fed at the same time.

The manager understood so imperfectly one of the important points in the matter, that he placed his experimental works on the creek, about two hundred feet below his stamp-mill. The ore was crushed to a diameter of $\frac{1}{4}$ to $\frac{3}{8}$ inch by a Dodge breaker, screened by hand, and jigged. The whole arrangement was crude, and required much manual labor. The tailings of all sizes were run to waste, no recrushing of dradge; no amalgamation. It was impossible to obtain samples of either ore or concentrates, or any data upon which to base a calculation, to determine the quality of the work. The only answer given to inquiries, was that it "did not

pay." This result is not to be wondered at, considering the crude methods, small scale and incomplete treatment. Since then nothing better has been tried, so far as I know, in the way of carrying out the metallurgist's suggestions.

Some years later, dressing-works were erected in Black Hawk, Gilpin county, on North Clear Creek, to do custom-work. The ore was crushed in a breaker and rolls, and treated on Collom jigs and buddles. The tailings were discarded, no attempt being made to crush as fine as would be necessary to save included grains of pyrites, or to crush very fine and amalgamate. This enterprise proved a failure. Since then, as I learn, the works have been remodelled, other jigs have been adopted, and stamps have been added for the treatment of the tailings from the coarse-grain jigs. The ore is crushed in a rock-breaker and three pairs of rolls; is sized through 4-, 6-, and 8-mesh screens, and these coarser sizes are passed over jigs. The tailings from these are crushed by stamps weighing about 500 pounds, having a drop of 14 inches, and making 36–38 drops per minute. Stamping is done, presumably, through 40-mesh screens, and the stuff passes over amalgamated copper-plates outside the batteries. *After* amalgamation, the slimes are treated on slime-jigs and buddles. Here, I wish to call attention to the error in this treatment. Stamps are unsuited to prepare ores for dressing in which the valuable portions are friable, such as those containing the sulphides of the base metals. Even with fast speed and short drop, stamps produce, when crushing to, say, 30-mesh, nearly three times as much slime, *i.e.*, stuff below $\frac{1}{200}$-inch in diameter, as good rolls crushing to the same size. With Gilpin county stamps, which have a high drop and slow speed, the product is still worse, *i.e.*, worse for dressing. If the coarser tailings from the jigs in this mill were crushed fine, by suitable machinery, the final tailings, to be treated by amalgamation, would be too fine to be fed under the stamps, unless they could be fed together with much coarser material. It would, however, be perfectly feasible to obtain, by other machinery, the finer comminution of the product required for amalgamation. The limit of fineness of stamp-stuff is, probably, 8-mesh, or, say 2 mm., in diameter. This is the reason why the tailings of the 4-, 6-, and 8-mesh stuff are fed directly to the stamps. And, as long as the Gilpin county mill-men insist on preparing ore for amalgamation by their favorite stamps, so long will a comprehensive method like that outlined by the metallurgist fail to receive a fair trial at their hands.

I have had no opportunity of examining this mill myself. It is

said, that it cannot compete successfully with ordinary gold stamp-mills, except when treating ores carrying galena, or a good deal of pyrites. The charge for treatment is $2.50 per ton, and the capacity is 25 tons with 6 men, or 4.16 tons per man. Considering the size of the stuff treated, this capacity is very small. Though the ordinary stamp-mill, in which a certain portion of the pyrites is recovered *after* amalgamation, does not return as much of the value of the ore as the other mill, its charge is so much less that the former must save from $1.25 to $1.50 more per ton in order to compete with it successfully.

E. E. Olcott, New York City: Much has been written on the subject of gold-milling, including papers by Dr. Raymond (*Trans.*, i., 40); Professor H. S. Munroe (*Trans.*, ix., 81); Professor Egleston (*Trans.*, xii., 379); A. N. Rogers (*Trans.*, xi., 29); A. J. Bowie (*Trans.*, x., 87); Professor H. O. Hofman (*Trans.*, xvii., 498); and John Hays Hammond's "Milling of Gold-Ores in California" (*Eighth Report of State Mineralogist*, 1888, p. 696).

I learn also, that Messrs. J. Ross Browne and John Hays Hammond are, at the present time, writing a book on stamp-milling.

While, as has been pointed out by Mr. Rickard, the mechanical defects of the stamp-mill are apparent, the advantages of the system are numerous. Its simplicity, adaptability, and uniformity of work, are good points in its favor. The new machines which have been put on the market with the claim that they would supersede the stamp-mill, have been numerous, but, so far, they have been unable to silence their clumsy prototype. The stamps still pound on, and are likely to continue to do so. Mr. Rickard has likened them to hammers. The ingenious inventor may get up a hammer, rule, and screw-driver, all in one, which may please the lover of novelties, but the skilful workman wants the old tried tools, not alone from prejudice but because he can do better work with them.

Wear and Tear.—The facility of renewing the wearing-parts of the stamp-mill is not an insignificant advantage, and counteracts in some measure the heavy consumption of iron per ton of ore crushed, and the necessity of discarding the castings before they are entirely consumed.

The shoes and dies are made of either iron or steel, experience varying greatly as to which is most desirable—much naturally depends on the hardness of the ore. As Mr. Rickard says, the die should be softer than the shoe. It is sometimes made of mild steel, and the shoe of chilled iron. Excellent results have been obtained

by me with mottled iron, a mixture of 85 per cent. hardest white iron and 15 per cent. of tough gray iron.

Iron shoes and dies last from one to three months in wet crushing, and the consumption of iron in the mortars averages about 1¼ pounds per ton of ore crushed. In South Africa, where the quartz is both hard and tough, the consumption of iron is high.

Messrs. Fraser & Chalmers are now manufacturing shoes and dies of what they call ferro-alumina, a highly crystalline hard white iron. Chrome-steel and Bessemer forged steel have been used with excellent results. Anything that increases the life of the wearing-parts of a mill is important, for we have not only to take into consideration the cost of the castings and the labor of repairs, but also the loss of time, interruption to amalgamation, and the escape from the battery of unground ore every time the battery is opened. It is evident, also, that the work done by shoes and dies, that wear down evenly, is greater than where the faces become irregular and uneven.

In localities remote from the base of supplies, a cupola connected with every large stamp-mill is very desirable. In it, with ordinary skill, the old iron can be recast, and, by varying the percentage of white and gray iron, and even old steel, excellent wearing parts can be made.

The screen is important. Formerly, slotted or punched Russia iron was almost always used, but of late, brass, phosphor-bronze, aluminum-bronze, and steel wire-cloth, have been employed, on account of their greater discharge-area. I have used phosphor-bronze screens in silver mills with the best results. By ordering the wire slightly heavier than in standard brass screens, a wear was secured several times that of the best brass screens that could be purchased. Aluminum-bronze is said to give as good results—in one case wearing 17 weeks, as against 3 weeks for Russia iron. Russia-iron screens last from 5 to 30 days, average 15 days.

Cams and tappets are now usually made of cast-steel. Cams last from 1 to 3 years; the average in the California mill, Nevada, is 16 months. Tappets should last 4 or 5 years.

Practice in Different Localities.—Mr. Rickard makes a comparison between Gilpin county, Colorado, practice and the more generally adopted California milling. The latter is unquestionably the best for most ores, and was adopted in the Black Hills, South Dakota, with few modifications.

As Prof. Munroe pointed out in the *Trans.*, ix., the gold stamp-mill may be described as a combined crushing and amalgamating

apparatus. The intimate admixture of quicksilver with the ore, by the swash in the battery, assists amalgamation; and copper plates inside the battery are to be recommended, except in cases where the percentage of sulphurets in the ore is very high. A good rule is to get your gold as soon as possible; and the following table, furnished by Mr. E. L. Young, will show, among other things, what a large proportion of the gold is saved inside the mortars in three mills, in Amador county, California:

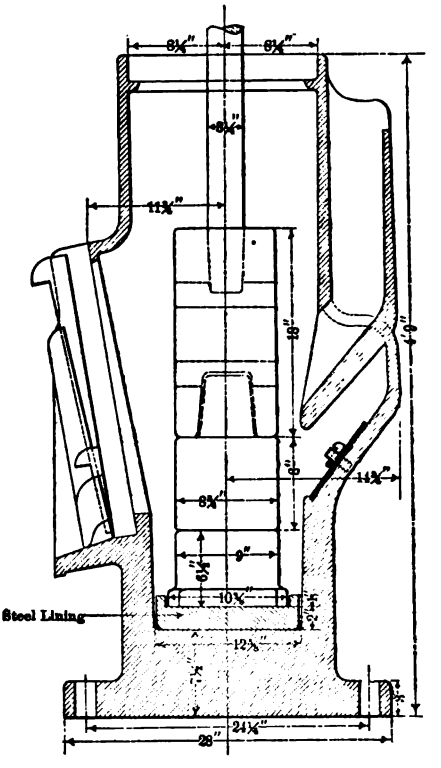
	Keystone. Water Power.	South Spring Hill. Water Power.	Stewart. Water Power.
No. of stamps,	40	30	40
Weight, pounds,	750	750	850
No. of drops per minute,	96	90	85
Duty per stamp per 24 hours, tons,	2½	2½	4½
Screens, slot-punched Russia iron,	No. 8	No. 7	No. 6
Miner's inches of water per 24 hours,	125	70	100
Head of water in feet,	254	325	200
Cost of mining per ton,	$3.50	$2.50	$0.40
Cost of milling per ton,	.75	.65	.20
Percentage of amalgam saved in batteries,	.85	.65	.60
Percentage of amalgam saved on plates,	6.7	30	40
Percentage of sulphurets,	1½ to 1¾	1	¼ to 1
Value of sulphurets, per ton,	$110	$125	$60
Cost of working sulphurets, per ton,	$20	$20	$20

Some Stamp-Mill Designs.—A diagram is presented herewith of a recently-designed gold-mortar. This is being built by Messrs. Fraser & Chalmers, for the Phœnix mill in Arizona. There is a recess for a copper plate at the back; but it is intended to use the battery without a copper plate in the front. In order to equalize the height of the discharge, iron filling-up pieces are intended to be used under the screen, so that when new dies are put in, three thin filling-up pieces will be put under the screen, and as the die wears down these can be removed, one by one. A more common means is to make the top bar of the screen-frame a little narrower than the bottom, so that by reversing the top and bottom of the screen different heights of discharge are obtained. The introduction of the steel lining-plate under the dies seems a doubtful experiment, though steel liners round the inside of the mortars above the dies are good.

The outward inclination of the screen (8° to 10°), spoken of by Mr. Rickard, is to be recommended.

Double-discharge mortars have never seemed to give satisfaction for gold-milling; theoretically they should effect a saving, but our best mill-men do not believe in them.

I am inclined to consider as purely imaginary the grinding action on the ore, produced by the turning of the shoe on the die. Practi-



Improved Mortar for Gold Stamp-Mill.

cally speaking, the stamp turns only when being lifted, and drops almost straight; the principal object of this rotation is to cause the cam and tappet, and the shoe and die, to wear more evenly.

In the West, axle-grease is usually employed on the face of the cams, but the practice in South America is to use molasses and water, so as to avoid any grease falling on the copper plates.

The cost of breaking rock in the crushers is far less than under the stamps, hence every mill-man should see that as much work as

possible is done by the rock-crushers. When the ore coming from the mine is in very large pieces it would pay well to have a large-sized rock-breaker feeding into two smaller ones, so that the work of the stamps may be reduced to a minimum.

Various Notes and Comments.—I do not see how the rise in the temperature of the water caused by the friction in the battery can be sufficient to liberate bubbles of air which may float the slimed ore. Authorities do not agree with Mr. Rickard in regard to its being desirable to have the jar of the battery transmitted to the plates, but on the contrary say that they should be supported independently.

The amount of quicksilver employed in the gold-batteries varies according to the richness of the ore and the experience of different localities. In Venezuela, at the Callao mill, the practice was formerly to keep the amalgam, both inside the battery and on the outside copper plates, quite hard. In the Black Hills, the amalgam is kept much softer. The amount of quicksilver that gold in different ores requires to make it adhere to the copper plates, can only be found by experiment. The coarser and purer the gold in the ore the smaller is the percentage of quicksilver required to form the amalgam. The loss of quicksilver is variable, depending on the amount of sulphurets in the ore, etc. Hammond gives the average loss as ½ ounce per ton.

Regarding the supply of water in gold-mills, they can be run when necessary on a supply of 500 to 700 gallons per ton of ore; but it is desirable to have if possible an allowance of 1000 to 1500 gallons per ton of ore.

Cost of Milling Ores in Various Localities.

Stewart mill, Amador county, California,	$0.20
At the Spanish mine, California, belonging to F. W. Bradley, the ore only yields 91 cents per ton. It is mined for 40 cents per ton, and milled in Huntington mills, at a cost of,	0.23
Treadwell, Alaska,	0.38
Deadwood Terra, Black Hills, South Dakota,	0.55
Homestake, Black Hills, South Dakota,	0.64
South Spring Hill, Amador county, California,	0.65
Keystone mill, Amador county, California,	0.75
Mr. Rickard gives for Gilpin county, Colorado,	0.95
El Callao, Venezuela,	1.18

Concentration and the Percentage Extracted.—There are very few

gold-mills in which it does not pay to concentrate the tailings, and treat or sell the sulphurets.

Frue or other vanners, revolving buddles, Colorado bumping-tables, and blanket-sluices are among the concentrators employed. The careful sampling and assaying of the tailings from all mills should be insisted on, so as to give absolute information as to the percentage of the gold that is saved. In the best mills in California the average results can be stated to be a saving of from 85 per cent. to 95 per cent. of the assay-value of the ore.

PHILIP ARGALL, Denver, Colo.: The limitations of the gold stamp-mill resolve themselves (according to Mr. Rickard) into the slow speed, long drop and high discharge, represented by the Gilpin county practice on the one side, and the fast speed, short drop and low discharge represented by the California practice on the other; while in the contrast between these systems he illustrates the very elementary axiom "that the treatment must be suited to the character of the ore." On this latter point, at least, we can all agree.

The high discharge is invariably used where fine crushing is desirable, or where stamping and pulverizing in one operation are necessary for the liberation of the fine gold. This practice is not by any means limited to Gilpin county or to any recent dates. As early as 1868, mills were running in Victoria, Australia, with drops of 18, 16, and 15 inches, the number of drops varying from 35 per minute upwards, and the weight of the stamp from 300 to 900 pounds.

At the Morro Velho mine, Brazil, the high discharge has long been used in the treatment of pyritic ores. Some carefully conducted experiments with high and low discharge at this mine, are given by Mr. J. A. Phillips, and are well worth quoting:

"With a 6-inch discharge, 75 per cent. of the stamped ore passed through a 120-mesh screen, and the loss in gold amounted to 44.70 per cent., while, with a 20-inch discharge, 87.5 per cent. passed through a 120-mesh screen, the gold loss being only 30.96 per cent. In other words, the high discharge reduced the material retained on a 120-mesh screen 15½ per cent., and thereby increased the gold-saving 13¾ per cent."

It is a well established rule that fast speed, short drop, low discharge and heavy stamps are to be used for coarse crushing, while for fine crushing, slow speed, long drop, high discharge and light stamps are in order. The point at which fine stamping should cease,

and from which the further pulverization of the ores should be conducted in Chilian or Hungarian mills, arrastras, or similar pulverizers, is not, however, very clearly defined.

The stamp is a very inefficient pulverizer, at best, and were it possible to get on the die at any one time all the fine particles requiring further reduction, the philosophy of lifting a 500-pound stamp 20 inches to crush these minute particles of ore, is not very apparent. Mr. Rickard claims that the turning of the shoe causes the abrasion of the surface of the gold, etc. This action is, I believe, so insignificant in the stamp-battery as to be almost unworthy of notice; and hence, when the grinding or abrading action is necessary to prepare the gold for amalgamation, resort is usually had to arrastras and similar grinding machines. This has been well illustrated at the Pestarena mine in Italy, where the best possible extraction with stamps did not exceed 65 per cent., while arrastras, in the form of the Frankfort mill, gave an extraction of 82 per cent.* The ores were principally iron pyrites, carrying the gold in minute particles, more or less enfilmed in micaceous schist. Not only fine grinding, but also time and *attrition* were found necessary for successful amalgamation.

Amongst the advantages claimed for the Gilpin county mills, we find the following:

(1) "The deep discharge causes the pyrite to remain in the mortar-box long after it has been pulverized to a size smaller than the screen-openings." Now, it is manifest that if the pyrites remained longer in the mortar than the other portions of the ores, the mortars would eventually be filled with pyrites to the depth of the feed used. This condition of affairs is not found to occur in practice. As I understand it, *all* the ores are retained longer in a deep mortar than in a shallow one; they are, therefore, crushed finer, and consequently the friable ores are reduced to an extremely fine state of division, and in great part converted into slime.

(2) "The long drop gives the interval of time required to allow the settling of the fine gold." The coarse gold, in all probability, settles in the mortar and is amalgamated; the fine gold, however,

* The report of the Pestarena Company for the year ending June, 1889, shows that 20.5 Frankfort mills were kept working for 309 days, treating 4,345,443 metric tons, giving an extraction of 81.1 per cent, with a mercury loss of 234 grammes per ton of ore treated. The figures for the following year are 5,724,004 metric tons treated in 25.9 mills working 344 days; extraction, 78.77 per cent.; loss of mercury, 230 grammes per ton.

would be thrown upwards by the splash, and caught in part on the copper plates, and in part discharged through the screens.

(3). "The roomy character of the mortar aids the deep discharge in affording a chance for the gold to get out of the way of the falling stamps, and to become amalgamated upon the copper plates." It is difficult to comprehend how the roomy character of the mortar, or the deep discharge can either jointly or severally afford a chance for the gold to "get out of the way" of the falling stamp, unless on the hypothesis that the gold is endowed with the potentiality of locomotion.

Mr. Rickard believes that the hammering which gold receives in a stamp-battery prevents amalgamation.

Professor Egleston says* that hammering gold on a smooth anvil with a clean, smooth hammer, prevented amalgamation; and he has further proved† that hammering gold in a clean mortar, under water, also prevented amalgamation. It is important to note that, in both examples, gold was hammered between smooth iron surfaces, an action that never occurs in a stamp-battery, in which the gold, if hammered at all, receives the pounding between rough and gritty ore, or at most, against but one iron surface—the result being the roughening and cutting of the gold flakes and particles, thus presenting new and clean surfaces to the mercury, and assisting the amalgamation. Indeed, Prof. Egleston's experiments confirm this view, for he found that when a freshly broken edge of the gold-plates came in contact with mercury, in every case it amalgamated at once. I have never found hammered unamalgamated gold in stamp-mill mortars where mercury was used, nor have I ever found a mill-man who has noticed such an occurrence. I am therefore warranted in the conclusion that the hammering (?) which gold receives in a stamp-battery does not prevent amalgamation. On the contrary, I think it has a beneficial effect on that process.

We are told that the metallic sulphides commonly occurring in gold-ores will be found, after stamping, in thin flakes and plates which readily float upon a running stream. These sulphides are iron, copper, and arsenical pyrites, zincblende, and galena, and I am not aware that they ever break up into plates and flakes under the condition named; they are, however, carried in a sluggish stream, floating, as it were, but simply on account of their excessive fineness.

The action claimed for the air in floating the slime in a mortar is, I presume, applicable to the California as well as to the Gilpin

* *Trans.*, ix., 648. † *Metallurgy of Gold, Silver, etc.*, vol. i., p. 587.

county mortar, if, indeed, it has any application at all. Now, the only way air can reduce the specific gravity of finely crushed ore, is by adhering in a fine film to the surface of the particles; and as the ore is wet from the moment it is put into the battery (and usually before it is put in) no air-film can form around the particles; therefore it is highly improbable that air gives the result claimed for it. As regards the heating of the water and air in a mortar, it must, under ordinary working conditions, be infinitesimal, probably not $\frac{1}{10}$ degree F. Of the many so-called contradictory features discovered in the stamp-mill, I will notice but one:

The vibration set up by the falling stamps is said to crystallize the iron work of the mill, and assist the work of gravity on the tables. I can see nothing contradictory in this. Vibration, under all conditions, will crystallize iron, and whatever good effect the vibration of the mill frame-work may have on the tables, it is not the same effect as the action of a jig.

The principal reason why the Gilpin county mill crushes less than the California is, that it does more work because it *crushes finer*, and that, as the agitation of the water is less, the ore is not discharged so freely. The loss in efficiency, due to the greater depth of water is caused only by the resistance of the stamp in passing through it, and not to the loss of weight, for this latter is the same when it is lifted as when it falls.

Pause, during which the particles can settle, is counted by Mr. Rickard as the time between the successive drops of each stamp, that is $\frac{60}{30} = 2$ seconds, but there is, in a 5-stamp set, a drop every $\frac{60}{5 \times 30} = 0.4$ seconds; consequently, the water in the mortar is agitated by 150 drops per minute; the only real pause at each stamp is the fraction of a second that it rests on the ore.

In comparing the amount of water used, it should be calculated per ton of material crushed. On this basis, there is no difference between the Australian and Colorado stamps; the former crushes $2\frac{1}{2}$ tons with 5 gallons, the Colorado 1 ton with 2 gallons, per minute.

The greatest defect in the stamp-mill as a crushing machine is in the discharge. The ore, even with a double issue, cannot escape from the mortars as fast as it is reduced to a fineness corresponding to the screen-openings, and it is consequently slimed. Particularly is this the case with pyrites and other heavy and friable minerals. This defect is augmented by the high discharge used in the Gilpin

county mills, and is claimed by Mr. Rickard to be made "an assistant to the mill-man." Now, if the greater part of the values were extracted from the pyrite, so that the tailings from the mills might run to waste, this practice would undoubtedly be the correct one to pursue; but inasmuch as the tailings are invariably concentrated, with a view to extract this very pyrite already reduced, in great part, to extremely fine slime, it is self-evident that "the mill-man's assistant" in the first operation becomes his adversary in the second.

There is always a danger in comparisons and generalizations. I therefore prefer discussing specifically milling under the conditions that obtain in Gilpin county; and to this end, it is obvious that one must take the whole process into consideration. Gilpin county milling is, in brief, fine stamping and amalgamating (very fully and clearly described in Mr. Rickard's paper) followed by concentration and smelting of the concentrated product. My experience is but that of an occasional customer of the mill. As such, I find the saving by amalgamation does not exceed 60 per cent. on average ores; and I freely admit that this is a good saving from ores carrying their principal values in pyrites. This statement of saving is confirmed by car-load lots that have been sampled at public samplers, and, afterwards, shipped to the mills for treatment, the complete returns of which I have had the privilege of examining, from time to time, as the tests were made. On straight iron pyrites, however, the saving by amalgamation in Gilpin county mills will not exceed 35 per cent. of the gold, as the following tests will show.

For the purpose of testing the extraction that could be made from pyrites, I had a carefully sorted lot of 11 tons put through a sampling mill, with the result that it assayed, gold, 1.06 ounces; silver, 1.74 ounces per ton. The ore was then shipped to one of the best mills in Black Hawk, Gilpin county, and the following result was obtained:

Gold saved.	Weight, oz.	Percentage saved.
By amalgamation,	4.08	34.99
In blanket-tailings,	1.52	13.04
In concentrates,	3.16	27.10
Total,	8.76	75.13
Silver saved.		
By amalgamation,	1.14	6.0
In blanket-tailings,	1.52	7.9
In concentrates,	7.14	37.3
Total,	9.80	51.2

	Pounds.		Gold, oz.	Silver, oz.
Weight of blanket-tailings, .	416	containing	7.30	7.30
Weight of concentrates, .	10,200	containing	.62	1.40
	10,616		7.92	8.70

The gold might be described as fairly coarse. A few colors could be obtained from almost every panning. The amount of gangue in the pyrites was about 5 per cent., leaving, say, 10.45 tons of pure straight pyrite. It will be noted, however, that about 50 per cent. of this was lost in the tailings, together with 25 per cent. of the gold and 49 per cent. of the silver; while the 50 per cent. saved as concentrates contained 40 per cent. of the entire gold and 45 per cent. of the silver in the original ore. The concentration of the tailings in the Gilpin county mills is conducted on end-percussion tables (bump-tables). Now, as we have seen that much of the pyrites is reduced to slime in the mortars, the loss in concentration is necessarily heavy. It varies, perhaps, from 20 to 50 per cent. of the pyrites contained in the ore. Some of the Gilpin county gold-ores contain a fair amount of silver, the greater part of which is lost in the milling-process.

The concentrates produced from the Gilpin county mills find a ready market at the Denver smelters, where the gold and silver are paid for at market rates, less 5 per cent., with a very moderate working charge, varying from $4 to $5 per ton.

It will be seen, that as the pyrites in the tailings is invariably concentrated and sold to the smelters, there is no gain in taking out part of its contained gold by amalgamation, more especially as in doing so, the ore is reduced to such a fine state of division that considerable loss is entailed in the subsequent process, a loss that far exceeds any advantage derived from extracting part of the gold in the mortars, and receiving the full market price for the gold so extracted. It appears, therefore, that concentration before amalgamation is the correct method to pursue in dealing with the average Gilpin county ores; and, in this connection, it is worth noting that this method is pursued in dealing with the *very coarse ores* from which the more or less solid sulphides are invariably picked out by hand and shipped direct to the smelters. It goes without saying, that if the principle is correct in the one case, it must be in the other; and if concentration by hand is applicable to pieces of ore from, say, one-inch cube upwards, mechanical concentration is equally applicable to the finer portion of the ore, as also to the mixed ores that require crushing preparatory to concentration.

I am fully aware that, in advancing the doctrine of concentration before amalgamation, I am going over old ground; nevertheless, I hold that it is the correct method to pursue, and, as such, cannot be set aside on account of the failure of previous crude tests, which were faulty in execution and incorrect in principle. Smelting is a very important step in the treatment of Gilpin county ores; without it, the present system of milling would cut but a sorry figure in the metallurgy of the West.

The full importance of smelting does not appear to be thoroughly understood by the mill-owners, and it is not to be wondered at that the full advantage to be derived from concentrating and smelting is neither admitted or practiced.

R. W. RAYMOND, New York City: Mr. Argall criticises Mr. Rickard's statement that the vibration of falling stamps on the one hand causes a pulsation of the water flowing over the plates, and, on the other hand, crystallizes the iron of the working parts of the mill. But Mr. Argall's criticism is, that these two features are not "contradictory," as Mr. Rickard has called them. The point is an exceedingly fine one. The evident meaning of the author is, that one of the effects he names is advantageous, and the other disadvantageous. But it is much more important to note that Mr. Argall is himself not "contradictory" of Mr. Rickard, as I think he ought to be, with regard to the alleged crystallizing effect of vibration on the iron of the mill. He goes so far as to say that, "vibration under all conditions will crystallize iron." This is, beyond question, incorrect. It is not even settled that vibration will crystallize iron under *any* conditions. Mr. Howe has compiled a summary of the evidence on the subject, adding an elaborate argument of his own to show that, possibly, vibration may sometimes have the effect mentioned; but the impression left by the whole discussion, is very strong, that, as a rule, the said effect does not take place as the result of vibration. Percy tried to find evidence of it, and failed. Stephenson found no change in a locomotive connecting-rod which had received 25,000,000 blows, at the rate of 8 per second; and he reported a similar absence of change in the beam of a Corliss engine which had received a shock of 50 tons eight or ten times a minute for twenty years. These, and many other pieces of evidence, will be found in Mr. Howe's book.* The fact is, that Messrs. Rickard and Argall have adopted a current fable, which may or may not have

* *Metallurgy of Steel*, p. 196.

a basis in occasional and exceptional experience, but which owes its vitality chiefly to its availability as an excuse to shield manufacturers from the blame deserved for bad work.

MR. RICKARD (communication to the Secretary): I wish to supplement the interesting remarks of Mr. Olcott by adding a few figures illustrative of some of those features of the stamp-mill to which he has made particular reference.

The consumption of iron by the wear of shoes and dies is dependent mainly upon the hardness of the ore crushed and upon the brittleness of the metal used. Table I.* gives the results obtained at eight localities working under very dissimilar conditions:

The minimum wear of shoes and dies amounts to 7.1 oz. of iron per ton of ore crushed, while the maximum is 25.4 oz., the average of the eight districts being about 1¼ lbs. Two facts are apparent from the examination of the tabulated figures. As would be expected, the life of the dies does not vary in an equal degree with that of the shoes, for the obvious reason that the ore upon the die serves as a cushion, protecting it from excessive wear. When that cushion of ore is not properly maintained, we get "low feeding" and an excessive abrasion, due to the working of iron upon iron. The importance of a regular feeding of the ore into the battery becomes very apparent when we look at the figures of those mills which do not employ rock-breakers, grizzlies and automatic feeding-machines. With the absence of these appliances, designed to produce a regular supply of pieces of ore of uniform size we find an excessive wear of shoes and dies, and more particularly of the former, for the reason already mentioned. In five districts scattered over different countries and in which the rock-breaker and feeder are not employed the wear of the shoe is never less than 10 oz. of iron per ton of ore crushed, while in the other three localities, where the mills are properly equipped, the wear never exceeds 7½ oz.

The successful use of wrought-iron dies at some of the Australian mills is worthy of note. Experience indicates that the minimum of wear and tear is to be obtained not so much by the use of a metal of excessive hardness as by making the die of a material more tough and less brittle than that of the shoe. Thus, steel working on iron, chilled upon unchilled, cast- upon wrought-iron, etc., all give better results than when the metal of the shoe is the same as that of the die.

* This Table accompanied an article on this subject by the writer in the *Engineering and Mining Journal* of September 23, 1893.

TABLE I.—*Wear of Shoes and Dies in Stamp Mills.*

	Name of District.		Metal.	Weight. New.	Weight. Worn out.	Ore crushed during time of service.	Metal worn per ton of ore crushed.	Cost of the metal per pound.	Value of the scrap.	Cost per ton of ore crushed.	Total cost per ton of ore crushed.	Remarks.
				Lbs.	Lbs.	Tons.	Oz.	Cents.	Cents.	Cents.	Cents.	
United States.	Gilpin County, Colo.	Shoes	Cast-iron	83	27	80	11.2	4	1	3.82	5.95	No rock breaker; no automatic feeders; ore moderately soft; long drop; wear of the dies is very variable.
		Dies	Same	48	26	78	4.5	4	1	2.13		
		Shoes	Chrome Steel	111	31	202	6.3	8	.....	4.39	7.15	Rock breakers and feeders; ore very hard; dies contain ¼ steel scrap.
		Dies	Same	55	25	159	3.0	8	.....	2.76		
	Grass Valley, Cal.	Shoes	Chrome Steel	152	48	251	6.6	9	1⅛	5.17	9.43	
		Dies	Cast-iron	93	45	96⅓	7.9	4½	1½	4.26		
	Angels' Camp, Cal.	Shoes	Chrome Steel	175	40	585	3.6	9	.....	2.70	4.06	Rock breakers and feeders; ore soft; short drop.
		Dies	Cast-iron	96	35	275	3.5	4½	1⅛	1.36		
	Mammoth, Ariz.	Shoes	Chrome Steel	132	40	190	7.7	11	.....	7.64	13.14	Ore medium; rock breakers and feeders; no grizzlies.
		Dies	Same	120	37	240	5.6	11	.....	5.50		
Australasia.	Bendigo, Victoria.	Shoes	Cast-iron	180	38	115	19.7	2⅛	⅜	3.66	4.37	No rock breakers and no feeders; ore variable but medium hardness.
		Dies	Wrought-iron	98	26	335	3.4	2⅛	⅛	.71		
	Clunes, Victoria.	Shoes	Cast-iron	196	56	105	21.3	2⅛	⅜	4.67	5.55	No rock breakers; feeders used; ore almost entirely quartzose.
		Dies	Wrought-iron	138	30	420	4.1	2⅛	⅛	.88		
	Harrietville, Victoria.	Shoes	Fagot-iron	172	38	185	11.5	3⅛	.....	3.25	4.72	No rock breaker; feeders used; dies wear very irregularly.
		Dies	Same	84	37	200	3.7	3⅛	.....	1.47		
	The Thames, New Zealand.	Shoes	Cast-iron	170	51	185⅓	14.1	3	1	3.40	5.65	No rock breakers or feeders; ore of every variable hardness.
		Dies	Same	108	42	141	7.5	3	1	2.25		

In the matter of screens there is often a practice of false economy. The relative cost of one kind of screen as compared with another can usually be disregarded by the mill-man. In California the cost of the screens amounts to one cent per ton of ore crushed, and the mill-man will do well to leave the expense out of the question and procure that variety of screen which best favors the particular conditions of discharge which he requires.

Table II. gives the wear of screens at different localities:

In Australia the old-fashioned round-punched Russia iron still holds its own, though it must manifestly do very imperfect sizing as compared to wire-cloth. Thus, for example, the "grating" most commonly used at Bendigo has 143 round holes per square inch; these holes are 0.024 inch in diameter, so that the discharge area per square inch is only 0.064 sq. inch. A typical 30-mesh wire-cloth screen, made in San Francisco, has openings of 0.025 inch square. Assuming for the purpose of comparison that the openings in the latter instance are the same as in the former, as is very nearly the case, we find that the discharge-area of the wire-cloth per square inch is 0.51, or eight times that of the punched iron sheet.

The screen, as used in many mills, can hardly be looked upon as a device for sizing the ore. The peculiar kind employed in Gilpin county has straight alternate burr-slots which are 0.015 inch wide and $\frac{3}{8}$ inch long. There are five slots in a length of two inches, so that there is afforded a discharge-area equal to only 0.028 of each square inch. The chance of the exit of a particle of pulp is as 1 in 34. Some appreciation of this fact is shown by the local mill-men, since it is their intention to use a screen which will retain the ore inside the mortar long after it has been crushed to a fineness permitting its passage through the openings.

In looking over the figures given above it will have been noted that the life of the screens is subject to wide differences. This is due to a variety of causes. In Gilpin county, Colorado, for instance, the minimum is 16 and the maximum 80 days of service. When examining the mills of this locality I obtained the figures of five mills, and was much puzzled over the seemingly contradictory results exhibited. The explanation was found in the relative locations of the mills. They are all situated by the side of the creek which flows through Black Hawk, and, beginning with the mill farthest up the creek, there is a steady diminution in the service of the screens, commencing with 80 days and decreasing to 16. The uppermost mill receives comparatively clean water, and after hav-

TABLE II.—*Wear of Screens.*

Locality.	Description.	Fineness.	Wear in Days.	Tons Crushed.
Gilpin County, Colorado.....	Burr-slot Iron	50 to 60 mesh	16 to 80	80 to 450
The Thames, New Zealand.....	Round-punched Russia Iron	148 to 180 holes per sq. in.	5 to 6	45 to 54
Clunes, Victoria.....	Perforated Copper Plate	80 to 100 " " "	25 to 30	312 to 375
Otago, New Zealand.....	Round-punched Russia Iron	140 to 180 " " "	6 to 8	39 to 52
Ballarat, Victoria..... ...	Same	120 to 200 " " "	10 to 14	100 to 140
The Ovens, Victoria.....	Same	200 to 290 " " "	17 to 20	145 to 175
Amador, California.....	Angle-slot Iron Steel and Brass Wire	No. 7 & 8 or 35 & 40 mesh 20 to 30 mesh	25 to 45	275 to 475
Grass Valley, California.....	Tin Plate Round-punched	30 mesh	16 to 24	140 to 220
Bendigo, Victoria.....	Round-punched Russia Iron	115 to 170 holes per sq. in.	9 to 17	95 to 180
Charters Towers, Queensland.....	Burr-punched Charcoal Iron	200 to 225 " " "	3 to 4	35 to 60
Treadwell, Alaska.....	Angle-slot Iron	No. 7 & 8 or 35 & 40 mesh	20	300

ing used it returns it to the creek, together with the addition of a certain percentage of sulphuric acid, as sulphate of iron, derived from the contact of the water with the partially oxidized pyrites in the ore, under conditions favorable to a certain amount of solution. The water then passes on to the next mill, where its slightly increased acidity reduces the life of the screens from 80 to 73 days. This second mill in turn contributes its share of sulphates, which help to injure the screens of the third mill. At this point the very acid waters of one of the mines flow into the stream, and, moreover, before it reaches the fourth mill, the creek has washed the sides of banks of sand more or less charged with partially oxidized pyrites, so that when it at length reaches the two lower mills, the wear of the screens is measured by days instead of weeks.*

In a case of this kind the addition of quicklime is to be recommended. At Ballarat (Victoria) five pounds are added every twenty-four hours to each battery of five heads.

The effort to maintain a uniform depth of discharge is much to be commended, and the importance of such a uniformity is very generally overlooked. In addition to the devices mentioned by Mr. Olcott, I may instance the employment of blank strips of iron placed outside, and against the lower edge of the screen. These strips can be of various widths. When the discharge is thus heightened there will be a tendency to accumulate sand inside against the screen, and this will protect the screen from abrasion along its lower edge, where it is covered by the iron strips. I have seen this method used in New Zealand. Again, in Amador county, California, where the "chuck-block" is used, the uniformity of the depth of discharge is aimed at by the employment of chuck-blocks of various thicknesses.†

On the use of double-discharge mortars, much has been said; but, in spite of frequent recommendation, they have gone out of favor. The main point to be considered in this connection is, that the use of a back-discharge weakens the force of the issue through the front screen, and so gives results less than would be, at a first glance, expected. There is another objection, especially in dry regions, to the double-discharge, namely, the consumption of water is considerably greater. This in itself proves the smaller force of

* See also "Variations in the Milling of Gold-Ores," by the writer, in *Eng. and Min. Jour.*, N. Y., September 3, 1892.

† See a more lengthy description in the *Eng. and Min. Jour.*, N. Y., December 23 and 30, 1893.

TABLE III.—*Consumption of Quicksilver.*

District.	Loss per ton of Ore.			Remarks.
	Minimum.	Maximum.	Usual.	
Gilpin County, Colorado.....	3.7 dwts.	9.8 dwts.	5 dwts.	Inside and outside plates.
The Thames, New Zealand.....	12 dwts.	25 dwts.	14½ dwts.	Outside plates. Grinding in pans.
Clunes, Victoria.....	5½ grains	5½ grains	5½ grains	No plate amalgamation. Wells and barrel.
Otago, New Zealand.....	5 dwts.	8½ dwts.	7 dwts.	Outside plate amalgamation.
Ballarat, Victoria.....	2½ "	5½ "	5½ "	Outside plates and wells.
The Ovens, Victoria.....	4 "	19 "	9 "	Outside plates. Grinding in pans.
Bendigo, Victoria.....	6½ "	9½ "	7 "	Outside plates and wells.
Charters Towers, Queensland...	60 "	100 "	80 "	Outside plates. Grinding in series of pans.
Amador, California.....	2½ "	6½ "	4½ "	Inside and outside plates.
Grass Valley, California.....	11 "	15 "	12 "	Inside and outside plates.

the splash. At Clunes (Victoria), in the use of double-discharge mortars,* the consumption of water is from 8 to 10 gallons per stamp per minute, while at Ballarat, an adjoining mining district, with ordinary single-discharge mortars, it is usually at the rate of

* See *Eng. and Min. Jour.*, N. Y., Jan. 28 and Feb. 4, 1893.

TABLE IV.—*Cost of Milling.*

Mill.	Power.	Stamps.	Cost.	Year.
Hidden Treasure, Gilpin, Colorado.....	S. & Wf.	75	$0.78	1891
Gover, Amador, California.....	W.	20	0.53	1893
North Star, Grass Valley, California.....	W.	40	0.81	1888–90
Wildman, Amador, California.....	W.	30	0.47	1891
Britannia, Ballarat, Victoria.....	S.	40	0.56	1891
S. Clunes United, Clunes, Victoria.....	S.	60	0.54	1890
New Chum, Con., Bendigo, Victoria.....	S.	30	0.58	1891
Excelsior, Charters Towers, Queensland.	S.	50	1.95	1890
Saxon, Thames, New Zealand.....	W.	33	0.98	1892
Mountain, Thames, New Zealand.....	W.	40	0.90	1892
Phœnix, Otago, New Zealand.....	Wf.	30	0.70	1890
*Morgan, South Wales, Great Britain.....	Wf.	40	0.20	1891
†Phœnix, Wynaad, India.....	Wf.	20	0.64	1884
†Mysore, Kolar, India.....	S.	90	3 05	1892
†May, Con., Johannesburg, S. Africa.....	S.	20	3.15	1890
†Jumpers, Johannesburg, South Africa....	S.	100	2.40	1890
‡El Callao, Caratal, Venezuela.....	S.	60	1.08	1891
⁋Treadwell, Douglass I., Alaska.....	Wf.	240	0.35	1893

S. Steam. W. Water which is bought. Wf. Water which is free of cost.

5 gallons. The crushing capacity is 2¾ tons per stamp in the former, and 2 tons in the latter case.

The minimum loss of quicksilver, which has come under my notice, was at the South Clunes United Mill at Clunes, where it was 5½ grains per ton of ore. The maximum was that of the Caledonia

* With steam-power it was 52 cents, according to Dr. C. Le Neve Foster.

† These figures, which I owe to Mr. A. G. Charleton, are taken from his paper "The Choice of Coarse and Fine Crushing Machinery, etc.," *Transactions of Fed. Institute of Mining Engineers*, 1893.

‡ Mr. Hamilton Smith, Jr.

⁋ Company's report for half year ending November 30, 1893.

Mill at the Thames, New Zealand, where 1 ton of quicksilver was consumed in 2 weeks by 20 stamps.

Table III. indicates the loss at a number of localities.

In addition to the figures of cost of milling given by Mr. Olcott, I may contribute the data contained in Table IV.

In each of the cases given in this table the cost of transportation is omitted. The cost of water-power in California is usually about 20 cents per miner's inch (or 1.57 cubic feet per minute). At the Gover Mill this expense amounts to from 18 to 20 cents per ton of ore, while at the North Star it is 31 cents, so that, including the cost of power, the milling was done at these two thoroughly representative plants, at the rate of 33 and 50 cents per ton respectively. The ore crushed at the North Star is particularly hard. The use of grinding- and amalgamating-pans increases the cost at the mills of Charters Towers (Queensland) and the Thames (New Zealand). At the Phœnix (N. Z.) no plates, but blankets only, are employed.

The question of the turning of the stamp is referred to by Mr. Argall and Mr. Olcott. The amount of the revolution is dependent upon the height and speed of the drop, and upon the amount of grease upon the cam. Occasionally, when the cam-surface has too much lubricant upon it, the tappet slips past without causing any observable turn. At four different mills, working under dissimilar conditions, I have noted the turn to be as follows :

	Stamp, lbs.	Drop, inches.	Speed per min.	Amount of Turn.
Hidden Treasure, Gilpin Co., Col. . .	550	17	31	1 to 1½ revols. per drop.
Garden Gully United, Bendigo, Victoria,	780	9	80	1 revol. in 4 to 9 drops.
Harrietville, Ovens, Victoria, . . .	700	8	70	1 revol. in 4 to 7 drops.
North Star, Grass Valley, Cal., . .	850	7	84	1 revol. in 5 to 6 drops.

As to the practical effect of the turn there is evidently much question. If the stamp turns as it is being lifted, it must continue to turn slightly after the cam has passed from under it. That the result, as far as it affects the ore upon the die, is insignificant in most cases, may be admitted; but it is supplemented by another factor, namely, the inequalities of the surface of the shoe. The effect of the latter is various, sometimes causing the stamp to move bodily out of the vertical (a movement soon checked by the guides),

and at other times causing a revolving motion. The die, of course, also wears unevenly, but as it is covered with ore, this fact has not the importance in this connection which must be allowed to that "cupping" of the shoe which promotes an irregular grinding action against the ore.

The use of a modern form of the arrastra at the Pestarena Mill, is quoted. The extraction, according to the report of the company, was 81 per cent. in 1888–89, and 78 per cent. in 1889–90. The loss of mercury in the respective years was 230 and 234 grammes per metric ton, equivalent to about 7½ pounds per short ton. The capacity of each mill was two-thirds of a ton per day. No doubt machines of the arrastra type will, in many cases, give the best conditions for promoting amalgamation; but, as compared with the stamp-mill, most machines of the grinding class have a very small crushing capacity, and consume a great deal of mercury.

In commenting upon my description of the Gilpin county milling practice, Mr. Argall has made a series of verbal criticisms which seem to me unnecessarily hypercritical and occasionally unfair. I reply to them only so far as to make my meaning plain, using the numbers employed by Mr. Argall.

(1) He points out "that if the pyrites remained longer in the mortar than the other portions of the ores," certain results would follow. I ask him to refer to the paper which he is criticising, when he will find that he has no warrant for saddling me with any supposition such as that which he is needlessly controverting. I was emphasizing the fact that the main idea of the Gilpin county method is to retain the ore inside the battery longer than is necessary for pulverization, in order to give more opportunity for amalgamation. The ore is mainly pyritic, and it is the pyrite that is immediately associated with the gold, therefore I spoke of the pyrites remaining in the mortar longer than was necessary for crushing purposes, but not "longer than the other portions of the ores."

(2) My statement that "the long drop gives the interval of time required to allow the settling of the fine gold" is true. All the gold of the ordinary Gilpin county ore is fine, and because it is fine, the present system of reduction is employed. The character of the amalgam, and the low retort yield, are indicative of the minute subdivision of the gold particles. There was no comparison made or intended by me between the "coarse" and the "fine" gold in the ore, and Mr. Argall controverts his own imagination.

(3) It is quite possible to comprehend my statement without sup-

posing the gold to be endowed with "the potentiality of locomotion." The deep discharge and the roomy mortar, both "jointly" and "severally afford a chance for the gold to get out of the way," because the depth of the one and the roominess of the other prevent the making of a violent splash, such as is produced in a narrow mortar with a shallow discharge; and the smaller force of the splash prevents a rapid exit of the pulp through the screen, and enables it to remain inside, so that the gold which it contains may be collected by the mercury lying at the bottom of the mortar, and by the amalgamated surface of the inside copper plates. If the discharge were shallow, and the mortar narrow, the gold could hardly get out of the way of the falling stamp without making its exit through the screen, and therefore, in the case of ore carrying gold in the finely divided condition which characterizes the Gilpin county mill-stuff, it would not be possible to save more than a very small percentage inside the battery. It is indeed true that in California and Australia a good proportion of the gold is often arrested inside the mortar, but such gold is considerably coarser than that caught upon the amalgamated tables outside; and, moreover, the ore itself is of a different nature, and the gold is essentially less fine than that treated by the mills of Gilpin county.

Referring to the interval which occurs between the successive drops of the stamp and the pause which is thus occasioned, enabling the particles of gold to settle and become amalgamated, I remarked that "in a Colorado mill the interval is two seconds; in California it varies from three-fifths to two-thirds of a second." This was said in comparing the relative frequency of the agitation to which the water in the mortar is subjected by the action of the falling stamp. It is quite unnecessary to point out that there are five stamps in each battery, and that therefore the duration of the interval should be divided by five. If we carry out this line of reasoning we shall conclude that there is no time of absolute quiet, for when none of the five stamps of any particular battery are falling, the water is still being agitated by the concussion produced by the stamps falling in the mortar boxes on either side.

As regards the warming of the water in the mortar by the conversion of wasted energy into heat, I did not consider it very considerable; but it may be, nevertheless, sufficient to add to the solubility of certain portions of the ore—as, for instance, partially oxidized pyrite. A careful test made at the Gover mill, Amador, California, gave the following results:

Test of the Temperature of the Water before and after leaving the Batteries, January 10, 1894.

	Before.	After.	Temp. of air.
8.30 A.M.,	37.0°	40.0°	40° F.
"	38.0°	40.5°	"
"	38.0°	40.5°	"
3.30 P.M.,	43.0°	44.0°	50° F.
"	43.0°	45.0°	"
"	43.5°	44.5°	"
"	43.0°	45.0°	"
4.30 P.M.,	42.0°	44.0°	48° F.
"	42.0°	45.0°	"
"	42·0°	45.5°	"

In his criticism of my statement that the retention of the pulp within the mortar, long after it is pulverized to a fineness permitting exit through the screen, has been used by the Gilpin county mill-man to assist him in obtaining the conditions which he desires, Mr. Argall has missed the main principle, repeatedly emphasized by me, of the milling-practice which he is discussing. The methods in vogue in Gilpin county originated in no idea of concentrating; if they had, then the excessive sliming of the pyrite, due to the deep discharge, would be a stupid blunder. On the contrary, however, the practice of the district is founded upon the principle of using the mortar, not only to crush the ore, but also, as far as possible, to make the mortar an amalgamating-machine. The introduction of percussion-tables for concentrating the pyrites in the tailings is comparatively recent. The mill-man's intention is, to save as much gold as possible inside the battery, and to do this by retaining the pyrite (with which the gold is mainly associated) inside, until a separation has been brought about; and these ideas are carried out by having a roomy mortar, a long, slow drop, and a deep discharge—more especially the last, which assists in procuring the condition he considers the most favorable to his purpose.

A statement was made, more than once, at the Chicago meeting, which does not, however, appear in the printed discussion, namely, that while the Californian type of stamp-mill has been introduced in mining regions all over the world, that of Gilpin county has not passed outside its own *habitat*. This statement is not quite accurate, since mills of the Colorado type have been successfully used in Dakota, Montana, Arizona, and Idaho; but, broadly speaking, it is no doubt correct to say that the Californian type is, by far, the more widely employed. Upon this fact is founded the suggestion that

the methods of "the little kingdom" of Gilpin are not thought worthy of imitation. In commenting upon this matter, I trust I may be absolved from any charge of prejudice, since I have used both types of mills successfully, and have endeavored to discuss the advantages and disadvantages of both fairly. The explanation of the fact just referred to is somewhat as follows:

The methods in vogue at Central City and Black Hawk were evolved under unusual conditions, and have been retained under peculiar circumstances. The first mills introduced, in the early "sixties," were modelled on the Californian type, and had a quick, short drop and a shallow discharge. While the mines were still in the gossan, or surface quartz, everything went well; but as soon as the unoxidized pyritic ores were reached the extraction began to diminish fast, and finally, this diminution nearly put a quietus to stamp-milling. Then the smelter* came to the rescue, and prevented the cessation of mining during the years which elapsed until the mill-men, by a long series of experiments, arrived at the conclusion that a long, slow drop, and a deep discharge, gave the conditions most favorable to the successful treatment of their ores. When the present methods were adopted, nearly twenty-five years ago, there was no market for low-grade iron pyrites, and the ore, although containing from 10 to 25 per cent. of sulphides, would give up a large percentage of its gold contents when crushed in the deep mortars which had come into use as the result of a hard-bought experience. The old methods have been retained, but with the addition of percussion-tables, because now the smelters charge very low rates of treatment for pyritic concentrates. Smelting charges are $4.50 for concentrates,† and $12 for crude ore. Railroad freight to-day (from Black Hawk to Denver) is $1.50 per ton on material worth less than $30 per ton, and $2 per ton for higher-grade stuff. Small coal ("mine-run") is delivered at the mills for $1.60 per ton. These are some of the conditions which have tended to perpetuate a milling practice which is, in many respects, out of date.

On the other hand, the methods of Gilpin county have not been adopted extensively elsewhere, because it is rarely that ores rich in pyrites are found to be comparatively so free-milling. The Californian mill, moreover, in its typical form, is a crushing-machine, adapted to preparing the ore cheaply and rapidly for a great variety of after-

* The Boston and Colorado Smelting Co. commenced operations at Black Hawk in 1867. In later years the works were removed to Argo, near Denver.

† Or "tailings," as they are termed locally.

treatment, by plate-amalgamation, blanket-saving, pan-amalgamation, concentration, lixiviation, etc. It is as a crushing-machine, having its parts so arranged as to give a maximum of automatic handling of the ore, that the California mill is first of its kind. Compared with it, in this respect, the Gilpin county batteries are clumsy and incomplete; but, as an amalgamating contrivance for the treatment of a particular class of ore, they were well-conceived at a time when amalgamation methods had no competitor in cheap smelting. Thus, after all, we do but return to the truism, which is often forgotten in these generalizations, that the milling-practice to be introduced at any mine or in any district must be suited to local conditions, the most important of which is, of course, the character of the ore.

W. L. AUSTIN, Denver, Colo.: A word as to the "current fable" of which Dr. Raymond speaks. Stamp-stems being among the "working-parts" of a mill are, therefore, included by Dr. Raymond in the category of the iron that does not crystallize. It will have been observed by any one who has operated a new stamp-mill of the California type, with stamps dropping from 90 to 100 times per minute, that after his battery has been running 12 to 18 months, the stamp-stems begin to break. Moreover, they break off, as a rule, right above the stamp-head, though occasionally they snap off just under the tappet, and often it becomes a serious undertaking to remove the ends of the stems from these heads, or "bosses." On account of these breakages, the stems are made tapering at both ends, so that when one end has broken off it can be reversed. In due course of time a similar mishap usually overtakes the other end. In many cases the mutilated stem is then laid aside as a problem for some future manager to solve, and new ones are ordered from the manufacturers. Now, the breakages may, as Dr. Raymond says, not be due to crystallization of the iron—for, properly speaking, the iron (which should be the best quality of wrought-iron) originally used in their manufacture is crystallized, to begin with—but during the pounding which the stamp has been doing, some molecular change has taken place, changing the fiber into a structure coarsely granular in appearance. That such a change should take place is quite conceivable, for these stems are submitted to an unusual amount of jarring. The $3\frac{1}{8}$ inch stem weighs 363 pounds, and the $3\frac{1}{4}$-inch stem 390 pounds, while the aggregate weight of stamp, including stem, head, shoe and tappet, is over 850 pounds. Such a weight, falling 6 inches 100 times a minute, for 300 days in the year,

finds no parallel case in pump-rods or the connecting-rods of engines. As would be expected, when the shoe is allowed to fall on the die, the life of the stem is shortened. The fact remains that the stamp-stems do break, and the iron has the appearance of being what, in the absence of a better term, is technically known as "crystallized." There is a class of men engaged in milling throughout the West who have been brought up in mills and have made a business of running them. It is a common practice among these operators to take the stamp-stems out of the batteries and anneal them by heating, and hammering them when the limit of safe working has been reached. These men are not chemists, and had once their little foibles, among which was the harmless use of sage-tea and similar concoctions in their amalgamation-departments; but they are first-class, practical mechanics, and their experience and opinions in these branches of milling are entitled to respectful consideration. Among such men as these the fable spoken of by Dr. Raymond is still current. At one mill, which was under the writer's charge for a while, there was a man employed who was classified as mill-blacksmith. He was the highest-priced man carried on the pay-roll, and it was his special duty to repair the iron-work about the mill, anneal stamp-stems, etc. Considering the appliances at his command, he managed to perform what might be termed feats of blacksmithing, and among such was the piecing out and welding of 3½-inch stamp-stems in an ordinary horse-shoeing forge, so that they afterwards withstood the wear and tear of the battery. He always paid great attention to the careful annealing of such work; for it is the experience of mill-men that stems thus treated last much longer than when such precaution is neglected. To have rendered this annealing necessary, the fiber of the iron must have undergone some change by the long-continued jarring which the stems had received. One can easily satisfy one's self of the extent of this jar by taking hold of a stamp-stem while in operation. It will be found to quiver violently. If the molecular change which takes place among the particles of iron in a stamp-stem after long and continuous use, by which the fibrous texture is altered into a granular one, may not be termed a crystallization, what is the proper expression to employ for such a phenomenon?

DR. RAYMOND: Mr. Austin's remarks indicate a misconception on his part of the meaning of my statements concerning the alleged "crystallization" of iron by vibration. It was not in the least my intention to quibble over a word. If I were so disposed, I should take exception to his present assertion that the wrought-iron of which

stamp-stems are made is "crystallized," to begin with. The question in my mind, as I think a careful reading of my remarks will convince Mr. Austin, was, whether there is really a molecular change produced by vibration in wrought-iron or steel. When Mr. Austin triumphantly inquires what is the proper expression, if "crystallization" is not, to describe such a molecular change, he simply begs the question. It will be time enough to discuss the name when the existence of the phenomenon has been demonstrated.

Before considering the evidence as to *that* question adduced by Mr. Austin, I would recall that my own criticism was made upon the sweeping statement of Mr. Argall, that "vibration under all conditions will crystallize iron." This I pronounced to be, "beyond question, incorrect," and to this, my only unqualified assertion on the subject, Mr. Austin's argument does not apply. If his evidence proves anything, it proves only that iron is *sometimes* thus affected by vibration.

As to this more limited proposition, I must frankly say that I see no conclusive force in Mr. Austin's argument. The one fact upon which it rests is the breakage of stamp-stems after twelve to eighteen months' running and the granular appearance of the fracture. But the fracture of a fresh bar of iron can be made to appear granular without any prolonged previous vibration, by the condition of the fracture itself. *A granular fracture does not prove an altered structure.* If the vibration-theory were correct, the rest of the stamp-stem ought to be more or less altered in structure; and, indeed, other parts of the stem ought to be more affected than the parts where the breakages usually take place; for the two places mentioned by Mr. Austin, namely, "right above the stamp-head" and "just under the tappet," are precisely the points of *minimum* vibration. They are the points of maximum *stress*, due to the checking of vibration by the stamp-head or the tappet.

Now, it probably never occurred to Mr. Austin, or any of the practical mill-men on whom he relies, to find out whether the parts of the stem which vibrate most freely are molecularly changed by such vibration; but some experiments of this kind which have been made have revealed no such alteration.

The fracture of iron under repeated stresses, no single one of which would produce visible rupture, is a very different proposition, and does not necessarily involve molecular change. It is more probably due to minute ruptures between the particles of the metal, which finally aggregate to constitute visible fracture.

I cannot admit that the vibrations in a stamp-mill are more severe

or more likely to produce molecular changes than those to which railway-axles, marine shafts, and locomotive connecting-rods are subjected. In these departments, quite as much as in stamp-mills, the notion of "crystallization" by vibration is an old one, and the evidence in its favor is essentially that which Mr. Austin adduces, namely, the granular appearance of fractures, which, taken by itself, is quite inadequate.

If vibration produces molecular change, why should previous annealing prevent that change? As it would be manifestly impossible for Mr. Austin's mill-blacksmith to anneal the whole of a stem in a horse-shoeing forge, it must be that he annealed only the part which he had welded, which would be the very part out of which he had taken all effects of previous vibration. Such an annealing was very proper to remedy the unequal strains caused by the welding-process itself, and to prevent the piece from breaking under stress or shock. But as it left untouched the rest of the "crystallized" stem, it can scarcely be considered as regenerating a fibrous structure. Moreover, a fibrous structure cannot possibly be produced by annealing.

In short, while I have never denied the possibility of molecular change in iron due to vibration, I must continue to regard the proposition as unproved, and the burden of proof as resting upon those who assert it, in the face of numerous experiments and careful tests which indicate the contrary. Mr. Howe's conclusion, after a patient analysis of much evidence, is:

"To sum up, while vibration and shock often cause rupture under light stress, and while it is proverbially difficult to prove a negative, we have, I think, every reason to believe that the granulation and crystallization of iron under vibration and shock is a myth."*

Unquestionably, the notion of a mysterious change produced by vibration in the quality of iron has worked double harm in stamp-mill practice. On the one hand, it has been the convenient excuse of manufacturers, who declare the evidences of bad workmanship shown in fractures to be the result of subtle changes thus produced in originally sound pieces of good metal. On the other hand, mill-engineers, believing that the inevitable vibration would break anyhow, in the course of a few months, the jarring parts of their mills, have given too little attention to the distribution of stresses and shocks by which such breakages might be greatly delayed or wholly prevented. If they would lay aside their preconceived notions, and, disregarding even the opinion of the mill-blacksmith, study the me-

* *The Metallurgy of Steel*, p. 199.

chanical reasons for the liability of a stamp-stem to break just over the head or just under the tappet, I think they would find more significance in the way tappet and head are attached to the stem (so as to subject it to heavy side shocks at points where it is not made stronger than elsewhere) than in any amount of molecular speculation.

REVIEW OF AMERICAN BLAST-FURNACE PRACTICE.

Discussion of the Paper of Mr. Potter. (See p. 370.)

T. W. ROBINSON, Pueblo, Colo.: Mr. Potter's review is a striking testimony to the important part played by science in this branch of practice. But, the question arises, In which department has science effected most? The available raw material, the size of furnaces, the general design and equipment of the plant, and the daily management, are particulars, each of which contributes to the general result, while the effect of each merges into that of the others. The following notes concerning the operations of the furnace-plant of the Colorado Fuel and Iron Company (formerly the Colorado Coal and Iron Company), at Pueblo, may throw some light upon the question of their relative importance. This company operates three stacks, and when the plant first came under my observation, about nine months ago, the furnaces were constructed, equipped, and run as stated below:

Raw Materials.—The main sources of ore-supply were, as they still are, the Orient and Calumet mines of the company. The Breece and Morning Glory ores, mentioned below, were formerly brought from Leadville, but are practically now no longer used.

The Orient ore is a porous brown hematite, easily reducible in the furnace. The Calumet is a magnetite, very refractory in character, requiring preliminary roasting. Both are fairly uniform in composition. The Breece and Morning Glory are red hematites, resembling in appearance the soft ores of the Vermilion range, Lake Superior.

The coke here used is made of coal from the company's mines in southern Colorado, and is distinct from that produced by the company in the western part of the State. The structure is similar to that of Alabama coke.

The limestone employed is a calcite. The analyses are given in Table I. I would note, parenthetically, that I know of no section of the country presenting harder conditions for furnace-practice than these materials impose. Results cannot be measured by the more

favored south, much less can northern practice be intelligently used as a standard for comparison. An average analysis of all the iron made in December, 1892, on No. 2 furnace, and in January, 1893, on No. 3, is included below, as showing the results obtainable with the raw materials in question.

Capacity.—Table II. presents the dimensions of each stack, tabulated for ready comparison.

Equipment.—Furnace No. 1, first blown in in 1881, was equipped with three Cowper stoves, 15½ by 57 feet; eight cylinder-boilers, 40 inches by 65 feet; and two I. P. Morris & Co. blowing engines, with 84-inch stroke, 42-inch steam- and 84-inch blowing-cylinders. These raised the stock by a pneumatic hoist, besides furnishing blast for the furnace. The general plan and equipment tolerably well represented the progress attained in furnace construction twelve years ago.

Furnace No. 2, an old stack shipped from the East, was erected at Pueblo, in 1885, though not blown in until the latter part of 1889. The blast, furnished by two I. P. Morris engines (cylinders of the same dimensions as above), was heated by four Cowper stoves, 16 by 60 feet. Eight cylinder-boilers (40 inches by 65 feet) generated the steam, and the stock was raised by a Crane steam-hoist. The furnace had the advantage over No. 1 of the greater stove-capacity noted, and the additional blast saved by the steam, as compared with the pneumatic hoist. Otherwise, it was practically the same, in plan and general equipment, as No. 1. Both furnaces had the bosh protected by petticoat-jackets.

No. 3 was a modern stack, just completed, and not blown in until the latter part of November, 1892. She is equipped with three Cowper stoves, 18 by 70 feet. Fourteen two-flue boilers, 54 inches by 30 feet, furnish steam to two Mackintosh & Hemphill blowing-engines; cylinders 42 by 84 inches, 60-inch stroke. There is a Crane hoist; the bosh is cooled by iron plates; and the general plan and arrangement are good.

Management.—The time covered in these notes extends from the blowing in of No. 1 furnace, in 1881, up to and through the first month of 1893. Until November, 1892, the furnaces were under several managements, but always, I believe, in the hands of practical men, exponents of the old school. With the organization of the Colorado Fuel and Iron Company, during November, 1892, came the advent of the new practice.

In Table III. is given the best monthly record of each furnace up to February, 1893.

A study of Tables II. and III., taken in connection with the related data, shows that raw material and capacity of plant were practically constants, thus eliminating them from our comparison, while equipment and management are the variables to be considered in producing the gradual advance noted.

Table III. (Records A and B) shows that No. 1's record for October, 1890, is her best accomplishment during her twelve years' activity. The best results from No. 2 from her erection to November, 1892, were achieved in July, 1892. Both were obtained under the same manager; thus the personal equation of management is removed, and in comparing the two runs, equipment alone can assert itself.

No. 2 had the advantage over No. 1 of greater stove-capacity, probably equivalent to about 200° F. in blast-temperature, and little more blowing power; and the lines were better, though far from ideal. The burden in both cases presented little difference. What existed was rather in favor of No. 1 than of No. 2, by reason of the larger amount of refractory Calumet ore used on the latter. Here the change in equipment has apparently raised production about 3.5 per cent. Fuel was lowered considerably. How much, is not exactly known, as the record was not trustworthy.

In the same table, Records B and C permit a comparison of the best performance of No. 2 (July, 1892), under the old management, with her record of five months later, which brings the influence of management to the front. The new regime began in November, 1892. The record for the following month is given. No. 2 was banked August 1, 1892, and was started again November 2, 1892. During the shut-down no changes were made on the furnace, so the equipment was exactly the same in each case. The burdens in the two campaigns were even more closely alike than in the first comparison, while the December work was accomplished under the usual irregularities due to a long banking.

Management is thus shown to be credited with 40 per cent. increase in production the second month after the change. The fuel-consumption certainly shows a large improvement over the consumption of No. 1, though the comparison is masked by the influence of equipment.

Again, Records C and D of No. 2 for December, 1892, and of No. 3 for January, 1893, illustrate once more the influence of equipment. The management is the same, and the furnaces are practically equal in size. The raw materials are essentially the same, while the variation in the percentage of the ores used favors No. 2 over No. 3.

The increased power and the lines (equipment) are responsible for the 25.5 per cent. increase in production. In measuring the comparative economy attained in fuel, the more refractory nature of the burden should be considered.

Finally, Records A and D show a difference in the performances of No. 1 and No. 3 amounting to 88.5 per cent. increased production and an economy of 620 pounds coke per ton of iron, through changes in equipment and management alone.

TABLE I.

	Iron.	Silica.	Phos.	Lime.	Mag.	Alum.	Mang.	Sul.	Ash.
Orient ore.....	48.67	19.67	.026	3.57	.84	1.29	1.43	.078	.....
Raw Calumet..	60.53	8.24	.012	2.63	2.49	.64	.34	.760	.....
Breece ore.....	59.76	6.56	.041	.26	.52	1.87	.37	.169	.....
Morn'g Glory.	51.17	10.45	.....	.....	.....	.....	.....	.....	.....
Limestone.....	1.23	7.68	.033	49.06	.56	1.71	.32	.....	.....
Coke	.....	.....	.....	.....	.....	.....	.....	.56	21.90

	Silicon.	Sul.	Phos.
Pig-iron av. Dec. No.2	2.45	.036	.081
" " Jan. No.3	2.45	.045	.074

TABLE II.

	No. 1.	No. 2.	No. 3.
Capacity.....	11,900 cub, ft.	.....	11,000 cub. ft.
Height of stack.....	75 ft.	75 ft.	75 ft.
Diameter of bosh.....	18 ft.	16 ft. to 10 ft.	17 ft.
Height of bosh.....	31 ft. 8 in.	30 ft. to 6 ft.	25 ft.
Angle of bosh.....	79½°	79¾°	78°
Diameter of hearth	9 ft.	10 ft.	9 ft. 6 in.
Diameter of stock-line...	16 ft.	14 ft. 6 in.	14 ft.
Diameter of bell.....	9 ft. 7 in.	8 ft. 4 in.	11 ft.
No. of tuyeres.....	7	6	7
Size of tuyeres	5 in.	5 in.	6 in.
Hgt. of tuyeres ab. h'arth	6 ft.	5 ft. 6 in.	6 ft.

TABLE III.

Management.		OLD SCHOOL.		NEW SCHOOL.	
Record.		A.	B.	C.	D.
Furnace.		No. 1.	No. 2.	No. 2.	No. 3.
Best month		Oct., '90.	July, '92.	Dec., '92.	Jan., '93.
Tons produced in best month		2385	2464	3582	4497
Tons prod. best week of best month		626	679	788	1062
Tons prod. best day of best month		97	105	140	180
Lbs. coke per ton iron		2965	.....	2418	2345
Lbs. limestone per ton iron		2015	1763	1450	1378
Average of heat of blast		770° F.	No record	1018° F.	1223° F.
Ore mixture, pr. ct.	Orient	50.	65.7	64.80	46.03
	Calumet	12.5	21.5	26.50	53.97
	Breece	31.2	.5	8.70	.....
	Morning Glory	6.3	12.3	.....	.....

WILLIAM H. MORRIS, Pottstown, Pa.: The following notes and tables on the blast-furnace practice of the Pottstown Iron Company, are submitted, in the hope that they may prove of interest in showing how close to chemical requirements a furnace can be run. The iron was manufactured for use in the basic Bessemer process; the special soft steel made by the company requiring a uniform metal. Irons containing over 0.75 silicon, or 0.08 sulphur, were classed as misfits, though it was desired not to exceed 0.4 silicon, or 0.04 sulphur.

The ore-mixture consisted of 30 per cent. mill-cinder, 55 per cent. magnetites from New York and New Jersey, and 15 per cent. hematites—not an easy one to handle. The fuel was one-half anthracite and one-half coke. The furnace-stack was 17 feet in diameter at the bosh, 10 feet in the hearth, and 80 feet high, to facilitate the reduction of these hard ores. It is, perhaps, unnecessary to add that anthracite is a much more difficult fuel to handle than coke, owing to its friability under heat and pressure producing scaffolds, dust, and other irregularities in the stack; and our brethren who enjoy selected Connellsville coke are looked upon with envious eyes. Anthracite also burns more slowly, and the furnace drives correspondingly, so that our production, while comparing favorably with that of our neighbors' smelting ores more easily reducible, is not to be con-

sidered alongside of those highly-favored stacks using Connellsville coke and selected Lake Superior ores.

Six casts were made daily, and each one analyzed, as well as the slag; and the excellent results achieved are due to the close attention of our furnace-manager, William P. Morris.

The furnace was banked in March, 1892, owing to an oversupply of metal, and, after starting again, ran nicely till blown out in December, as will be seen by the following analyses, giving weekly averages of the metal made:

During the last seven months of the blast the misfits were only 5 per cent.; in July, 1892, the misfits were $1\frac{7}{10}$ per cent.; in August, the misfits were $1\frac{1}{10}$; in December, *nil.*

The weekly average analyses of the last thirty weeks of the blast show:

	Per cent.
2 weeks in which silicon averaged between	0.5 and 0.6
4 weeks in which silicon averaged between	0.4 and 0.5
1 week in which sulphur averaged between	0.07 and 0.08
1 week in which sulphur averaged between	0.06 and 0.07
1 week in which sulphur averaged between	0.05 and 0.06
6 weeks in which sulphur averaged between	0.04 and 0.05

All the rest came within the desired limits of 0.4 silicon, and 0.04 sulphur. The phosphorus was kept within 0.2 per cent. above or below the point given by the Bessemer manager by varying the ore-mixtures. This also required close attention to the ores. Phosphorus was, at times, as high as 3 per cent., and as low as 2.25 per cent. The production of metal averaged 850 tons weekly, the fuel-consumption under $1\frac{1}{10}$ tons per ton of pig.

TABLE I.—*Average Weekly Analyses.*

Week ending.	Silicon.	Sulphur.
April 16,	.569	.029
April 23,	.367	.043
May 7,	.271	.069
May 14,	.593	.034
May 28,	.420	.038
June 4*,	.415	.045
June 11,	.385	.043
June 25,	.159	.043
July 2,	.444	.024
July 9,	.422	.028
September 10,	.199	.043
October 29,	.218	.050
November 12,	.302	.053
November 19,	.120	.075

* The only week in which both elements exceeded the limits of 0.4 for silicon and 0.04 for sulphur.

TABLE II.——*Analyses of July*, 1892.

Date	Cast No.	Silicon.	Sulph'r	Date	Cast No.	Silicon.	Sulph'r	Date.	Cast No.	Silicon.	Sulph'r
July 1	1	.257	.035	July11	61	.327	.064	July21	121	.291	.039
	2	.257	.025		62	.210	.099		122	.210	.041
	3	.374	.040		63	.233	.121		123	.233	.055
	4	.444	.034		64	.303	.084		124	.163	.065
	5	.327	.027		65	.490	.037		125	.374	.033
	6	.327	.030		66	.525	.036		126	.385	.024
2	7	.327	.049	12	67	.514	.044	22	127	.280	.029
	8	.303	.046		68	.560	.048		128	.210	.020
	9	.291	.025		69	.607	.036		129	.291	.035
	10	.420	.018		70	.677	.045		130	.303	.022
	11	.303	.022		71	.397	.025		131	.140	.051
	12	.280	.019		72	.291	.030		132	.233	.020
3	13	.093	.033	13	73	.444	.016	23	133	.280	.031
	14	.210	.026		74	.490	.017		134	.397	.038
	15	.374	.020		75	.280	.046		135	.361	.047
	16	.327	.033		76	.374	.027		136	.374	.032
	17	.257	.025		77	.268	.030		137	.350	.038
	18	.420	.022		78	.291	.023		138	.548	.029
4	19	.385	.026	14	79	.350	.019	24	139	.501	.089
	20	.747	.016		80	.314	.013		140	.420	.044
	21	.747	.012		81	.268	.024		141	.374	.046
	22	.595	.016		82	.327	.029		142	.385	.044
	23	.210	.027		83	.397	.026		143	.560	.031
	24	.420	.040		84	.257	.037		144	.420	.032
5	25	.327	.043	15	85	.303	.029	25	145	.187	.080
	26	.314	.018		86	.303	.030		146	.244	.047
	27	.361	.032		87	.257	.027		147	.280	.039
	28	.374	.020		88	.303	.019		148	.163	.054
	29	.338	.020		89	.327	.023		149	.163	.076
	30	.338	.022		90	.374	.025		150	.444	.025
6	31	.327	.022	16	91	.268	.025	26	151	.374	.028
	32	.257	.028		92	.327	.026		152	.374	.030
	33	.397	.036		93	.514	.024		153	.303	.031
	34	.455	.027		94	.268	.023		154	.280	.024
	35	.397	.021		95	.163	.018		155	.187	.022
	36	.187	.040		96	.210	.018		156	.303	.029
7	37	.221	.042	17	97	.397	.031	27	157	.280	.022
	38	.548	.044		98	.408	.009		158	.537	.009
	39	.421	.043		99	.350	.009		159	.350	.022
	40	.350	.024		100	.374	.009		160	.303	.013
	41	.514	.017		101	.280	.009		161	.280	.011
	42	.444	.026		102	.268	.031		162	.361	.020
8	43	.350	.030	18	103	.350	.017	28	163	.303	.042
	44	.490	.040		104	.444	.018		164	.374	.023
	45	.607	.024		105	.374	.020		165	.397	.035
	46	.747	.014		106	.537	.019		166	.430	.030
	47	.654	.016		107	.303	.021		167	.374	.020
	48	.257	.039		108	.280	.021		168	.233	.020
9	49	.257	.045	19	109	.303	.024	29	169	.128	.032
	50	.631	.045		110	.327	.025		170	.374	.037
	51	.571	.039		111	.420	.031		171	.280	.036
	52	.537	.024		112	.560	.018		172	.303	.033
	53	.537	.017		113	.537	.017		173	.257	.026
	54	.514	.019		114	.701	.016		174	.327	.036
10	55	.501	.024	20	115	.467	.014	30	175	.257	.025
	56	.374	.032		116	.444	.016		176	.444	.019
	57	.070	.040		117	.537	.031		177	.397	.022
	58	.514	.030		118	.444	.022		178	.257	.020
	59	.303	.018		119	.654	.013		179	.269	.028
	60	.210	.046		120	.397	.035		180	.269	.024
	.....	.....	.....		.....	.....	.....	31	181	.257	.019
	.....	.....	.....		.....	.....	.....		182	.257	.027
	.....	.....	.....		.....	.....	.....		183	.210	.031
	.....	.....	.....		.....	.....	.....		184	.444	.031
	.....	.....	.....		.....	.....	.....		185	.315	.030
	.....	.....	.....		.....	.....	.....		186	.257	.026

TABLE III.—*Analyses for August*, 1892.

Date.	C'st No.	Silicon.	Sulphur.	Date.	C'st No.	Silicon.	Sulphur.	Date.	C'st No.	Silicon.	Sulphur.
Aug. 1	187	.350	.024	Aug.11	247	.163	.028	Aug.21	307	.186	.023
	188	.513	.021		248	.093	.038		308	.233	.025
	189	.402	.029		249	.257	.051		309	.139	.024
	190	.397	.009		250	.338	.020		310	.139	.025
	191	.315	.015		251	.257	.031		311	.116	.021
	192	.210	.026		252	.186	.028		312	.191	.025
2	193	.33	.019	12	253	.140	.031	22	313	.196	.027
	194	.257	.019		254	.292	.030		314	.373	.045
	195	.315	.030		255	.233	.038		315	.345	.049
	196	.210	.034		256	.140	.028		316	.340	.037
	197	.257	.038		257	.221	.017		317	.345	.026
	198	.210	.032		258	.350	.022		318	.363	.025
3	199	.257	.023	13	259	.374	.010	23	319	.312	.029
	200	.303	.026		260	.221	.023		320	.410	.030
	201	.420	.023		261	.227	.030		321	.423	.027
	202	.490	.019		262	.139	.020		322	.233	.017
	203	.315	.019		263	.186	.020		323	.233	.013
	204	.233	.021		264	.093	.017		324	.139	.086
4	205	.140	.051	14	265	.326	.019	24	325	.126	.046
	206	.374	.037		266	.186	.023		326	.139	.039
	207	.444	.023		267	.186	.021		327	.392	.026
	208	.467	.033		268	.233	.035		328	.116	.043
	209	.327	.025		269	.139	.070		329	.130	.029
	210	.221	.033		270	.233	.035		330	.107	.056
5	211	.210	.026	15	271	.280	.023	25	331	.130	.085
	212	.163	.049		272	.233	.030		332	.070	.080
	213	.104	.039		273	.233	.041		333	.186	.042
	214	.257	.046		274	.186	.045		334	.205	.040
	215	.163	.060		275	.139	.040		335	.326	.027
	216	.198	.041		276	.378	.020		336	.583	.021
6	217	.163	.025	16	277	.323	.018	26	337	.467	.020
	218	.257	.024		278	.326	.026		338	.402	.029
	219	.374	.025		279	.233	.039		339	.420	.035
	220	.257	.024		280	.280	.010		340	.256	.026
	221	.127	.021		281	.326	.010		341	.186	.018
	222	.104	.026		282	.280	.015		342	.349	.029
7	223	.127	.022	17	283	.139	.024	27	343	.153	.040
	224	.210	.032		284	.280	.038		344	.326	.037
	225	.397	.022		285	.320	.031		345	.401	.030
	226	.397	.032		286	.348	.027		346	.467	.031
	227	.233	.027		287	.326	.022		347	.233	.019
	228	.210	.027		288	.139	.021		348	.233	.034
8	229	.163	.027	18	289	.139	.021	28	349	.139	.027
	230	.257	.020		290	.3 6	.026		350	.281	.030
	231	.233	.021		291	.328	.025		351	.304	.020
	232	.257	.014		292	.107	.049		352	.440	.015
	233	.174	.012		293	.163	.023		353	.499	.023
	234	.280	.019		294	.443	.016		354	.280	.040
9	235	.327	.017	19	295	.256	.018	29	355	.186	.048
	236	.338	.016		296	.323	.026		356	.186	.026
	237	.327	.024		297	.280	.030		357	.578	.032
	238	.327	.029		298	.280	.030		358	.139	.022
	239	.142	.039		299	.233	.013		359	.256	.057
	240	.102	.022		300	.186	.022		360	.326	.052
10	241	.104	.041	20	301	.186	.016	30	361	.320	.026
	242	.163	.049		302	.326	.026		362	.217	.039
	243	.115	.036		303	.420	.035		363	.373	.043
	244	.186	.047		304	.209	.018		364	.139	.072
	245	.280	.040		305	.209	.026		365	.420	.031
	246	.233	.027		306	.163	.021		366	.233	.036
	.....	.....	.....		.....	.....	.....	31	367	.280	.039
	.....	.....	.....		.....	.....	.....		368	.231	.013
	.....	.....	.....		.....	.....	.....		369	.373	.012
	.....	.....	.....		.....	.....	.....		370	.380	.021
	.....	.....	.....		.....	.....	.....		371	.373	.017
	.....	.....	.....		.....	.....	.....		372	.326	.026

Analyses of each cast during the months of July and August are given in Tables II. and III.

The average weekly analyses for December, 1892, are believed to show pig-metal very remarkable for low silicon combined with low sulphur.

Week ending,	Silicon.	Sulphur.
December 3, ...	0.200	0.023
December 10, ...	0.181	0.033
December 17, ...	0.239	0.029

THE CONSUMPTION OF FUEL IN THE TAYLOR GAS-PRODUCER PLANTS AT THE ASPEN AND MARSAC MILLS COMPARED.

Discussion of the Paper of Mr. Stetefeldt. (See p. 134.)

WILLIAM H. BLAUVELT, Anaconda, Mont.: Mr. Stetefeldt's comparison of the producer-plants at Aspen, Colorado, and Park City, Utah, is of special interest at this time, when the attention of all western metallurgists is so forcibly drawn to the necessity of reducing expenses and losses.

The fact that wood was used at Park City before gas was introduced, for firing the Stetefeldt furnace and dryer, offered an excellent opportunity for showing the economies resulting from the adoption of gas in place of wood, as well as a comparison between the two gas-plants. Some time ago Mr. Stetefeldt contributed an article to one of the technical journals, in which the economy obtained by the substitution of gas for wood at this plant was shown quite in detail. I regret not being able to quote from his article at length, but remember that the total saving effected would pay for the producer-plant in about one month. This is a striking instance of the advantages to be secured by the adoption of the best methods of using fuel in our metallurgical works.

In comparing the figures from the Park City and Aspen plants, the difference of over 20 per cent. in the fuel used in the Stetefeldt furnaces, seems remarkable, even considering the larger amount of sulphur in the Aspen ore, and the greater rapidity with which it was roasted. It would be interesting to have Mr. Stetefeldt's opinion as to the cause of so great a difference.

The inferior economy of the revolving dryers at Park City might be overcome by lengthening them, or so arranging a second one above

the first, that the ore and heat would pass automatically through both; and by covering the outside with some insulating material.

I cannot agree with Mr. Stetefeldt regarding the superiority of unlined pipes for carrying gas. It is difficult to remove with scrapers the soot and tar from pipes more than, say, 25 feet long; and when no lining is used, it is generally necessary to introduce bends in the pipe, which would not otherwise be needed, in order to permit cleaning. Pipes can easily be lined to a diameter as small as 20 inches—and a smaller size is not desirable except for short branches. When pipes are lined with brick, a proper arrangement of draft permits the whole system to be burned out perfectly clean, with but little delay and no labor. Moreover, the lining of the pipes largely prevents strains from expansion and contraction, and diminishes very much the need of frequent repairs.

A study of the Park City and Aspen roasting-plants suggests a further improvement, which would undoubtedly materially increase the economies already obtained. The comparatively high temperature of the chamber below the second or auxiliary fire-place, should be utilized for preheating the air for burning the gas, and for oxidizing the sulphur. The use of hot air is very desirable in such a furnace, as it can be admitted in large enough quantities to thoroughly roast the ore without the chilling effect which the same amount of cold air would have.

The air can be heated to a high temperature by a system of properly proportioned cast-iron pipes, unless there is chlorine in the gases at this point, which seems hardly probable. In that case clay-pipes might be used, as in some of the recuperative glass-melting furnaces. But the sulphur gases do not materially affect cast-iron. In the use of a device of this kind, I have been able to maintain air at a temperature of 800° to 1000° F. for weeks at a time, when the iron pipes were constantly exposed to strong sulphurous fumes, without being able to notice any action of the sulphur upon the iron. In fact a thin coating of fume and dust soon covers the pipes, and this coating would itself doubtless prevent any chemical action on the iron.

Hot air should be employed, whenever possible, for the combustion of gas, for it not only returns to the furnace heat that would otherwise escape; but it also causes a more perfect combustion of the gas, and more rapid work.

In the roasting of ores more attention should be paid to the use of hot air. Faults inherent in a number of the systems now in use, could be largely overcome by this means.

GEORGE W. GOETZ, Milwaukee, Wis.: I do not share Mr. Stetefeldt's preference for spiral-weld pipes. My experience has demonstrated that it is cheaper to make pipes large enough to permit the introduction of a refractory lining.

Trouble experienced with producers at Great Falls influenced me to try Taylor producers instead of those of Wellman. But recent reports show that the Wellman producers work better, besides costing nearly 50 per cent. less than Taylor producers of equal capacity. Indiana and Illinois coals cannot be used in the Taylor producers, by reason of the large size and hardness of the clinkers which they form.

THE GENESIS OF ORE-DEPOSITS.

Discussion of the Paper of Prof. Pošepný. (See p. 197.)

W. P. BLAKE, Shullsburg, Wis.: I desire to express my admiration of Prof. Posepny's memoir, and particularly of the charming manner and spirit of the introduction.

With respect to his mention of the ore-deposits of Missouri and Wisconsin, reference may be made to my paper presented at this meeting (*Trans.*, xxii., 621), showing the existence of dislocations and breaks in the bedding, and their apparent close relation with the localization of the ore-deposits as claimed by Dr. James G. Percival, and also so claimed by Dr. Jenney in his paper before us (*Trans.*, xxii., 171). I have in my paper given reasons for believing that the zinc- and lead-ores in the strata above the compact Trenton limestones were formed by lateral secretion and concentration from above downwards, substantially as shown by Prof. J. D. Whitney, and not by the ascent of solutions through the fissures, as Prof. Posepny (p. 304) seems inclined to believe.

In regard to the contemporaneity of the ore and the rocks, and in favor of a later introduction of ore through fault-fissures, Prof. Posepny (p. 310) cites the influence of these fissures. In my paper, already referred to, I have endeavored to show how faults may have influenced the deposition of ore without being themselves channels for the flow of mineral solutions, and how they may have caused the contemporaneous formation of metallic sulphides from sea-water in the body of a forming rock; the faulting fissure being formed at an early period in the foundation rocks, and probably continuing to be a plane of break and movement in the deposits of later formation.

ARTHUR WINSLOW, Jefferson City, Mo.: The results of extensive and long continued studies, such as are here presented by Prof. Posepny, deserve most careful consideration before one should undertake to criticise the general conclusions or judge of the broader bearings of his work. I shall not attempt anything of the kind. The remarks made by me (*Trans.*, xxii., 634, 735) in the discussions of Mr. Emmons's and Dr. Jenney's papers, presented at this meeting, are to a great extent applicable here; but I wish to add a few more words bearing directly upon Prof. Posepny's statements concerning the Missouri and Wisconsin ores.

On page 303 he says that while the deposits, away from the granite and porphyry "islands" of southeastern Missouri consist chiefly of lead- and zinc-ores, "other metals, such as copper, cobalt, and nickel, occur as the Archean foundation-rocks are approached." This circumstance, he says, is "an indication that the source of the lead-deposits also is to be sought in depth." Whatever may be the value of this indication, I do not think the facts as stated hold generally. I judge that Prof. Posepny reasons from his observations at Mine La Motte, where such conditions exist. At other points, however, these changes in composition are not observed as the crystalline rocks are approached. At Doe Run, a mine recently opened, work is prosecuted along the old water-worn pre-Cambrian surface of the Archean granite, among the conglomerate boulders themselves; and few or no copper-, cobalt-, or nickel-ores are found. Again at other localities, in St. Genevieve, Franklin, Crawford and other counties, copper-ores occur remote from any granite or porphyry outcrops and well above the basal beds of the Cambrian.

With reference to the Wisconsin deposits, our author seems to think the absence of ores, in the great thicknesses of limestones and sandstones which underlie the productive horizons, by no means conclusive as an argument against their deep-seated source, and suggests that the solutions may have come up through a passage not yet exposed, and even that fault-fissures and eruptive dikes may exist which have not been discovered. From the fact that he refers in this connection only to Whitney's report of 1862, I conclude that he has not had access to the later and more exhaustive works of Strong and Chamberlin. Perhaps with the full light conveyed by these reports and accompanying maps, Prof. Posepny might have attached more importance to the objections raised. For my own part I do not see how such a passage for the solutions as he suggests could possibly exist without its presence having been revealed and its

course traced, through the widespread mining and exploring which has been conducted in this region during the past seventy years. Neither do I yet see how the solutions could traverse the intervening great thicknesses of water-soaked sandstones without becoming diffused, in great part at least. The failure to find such a passage and the absence of the ores in the beds assumed to have been traversed, though evidence of a negative character, is so strong that it becomes of almost positive value in support of the theory of lateral segregation.

T. A. RICKARD, Denver, Colo.: The distinguished author of this paper has referred to the Leadville monograph of Emmons, as "epoch-making." This judgment has been anticipated, I believe, by most of us. It serves, however, very well to recall the fact that the publication of that particular monograph marked the high tide of the lateral-secretion theory, which owed its importance more to the fact of its acceptance by certain distinguished geologists than to its incomplete demonstration by Sandberger.

What Prof. Posepny said of the work of our American geologist we can say, with even greater force, of his present contribution. His dissection of the theory promulgated by Sandberger is most effective. The sympathies of the miner are with him in that demolition of the lateral-secretion theory; for the latter was an explanation which never found much favor underground, with the miner, but had its stronghold in its own particular *habitat*, the professor's *sanctum*. Here I would throw out the suggestion to my fellow mining engineers, whose business is to observe rather than to theorize, that these distinguished scientists must, after all, look to the men who spend much time underground for the accumulation of evidence whereon to found their hypotheses. If the genesis of ore-deposits is to be unravelled, more particularly if this study is destined to be capable of further practical and economic application, it must be through the gathering of facts and not the mere building of theories. Prof. Posepny has very properly pointed out that Sandberger's views gained many disciples because they permitted extensive generalizations to be made above ground, and in comfort, but did not so much require a descent underground and the making of observations under conditions of discomfort. Therefore, I would say, let those of us who have the opportunity aid in the elucidation of truth by the collection of the facts and observations without which speculations regarding the origin and formation of ore-deposits are worse than vain.

Prof. Posepny emphasizes the fact of the ascension of mineral

solutions. I venture to suggest that these terms—"ascending," "lateral," and "descending"—may all be applied to mineral solutions at various periods and under various conditions. It is the great fact of *circulation* which covers all. The water which comes up must have first gone down; its original descent was as necessary to the process of ore-formation as its subsequent ascent. When and where in its journeying it became a solvent and when and where it became a precipitant—that is what the miner wants to know. The ultimate formation of an ore-deposit is dependent more upon conditions favoring precipitation than upon those determining solution.* Prof. Posepny points out more than once, that the two great factors which increase the solubility of all substances are heat and pressure. We know by observation that these conditions are increasingly obtainable as we go downward. The deep region is one that favors solution, just as the shallow zone, because it is characterized by lessened heat and diminished pressure, favors precipitation. It is this simple fact which helps to explain the ordinary non-persistence of ore in depth. It is this which explains the comparatively late origin of ore-deposits. The general non-persistence of ore in depth is a fact capable of proof, the comparatively late origin of most ore-deposits is a hypothesis which is founded upon observation and confirmed by the consideration that the older geological formations were at some time overlaid by an enormous thickness of later sediments and therefore existed under conditions favoring solution, and not that precipitation to which ore-deposition is more directly due.

One more point I would wish to refer to. Prof. Posepny demonstrates that at Przibram the metal of the ore-deposits could not have come from the eruptive rock in the immediate vicinity of the lodes. This is most interesting. For many years we have been accustomed to references to dikes and other bodies of eruptive rocks as being the source of the precious metals of certain lode-formations. In fact, a "dike" was almost as necessary as a "true fissure-vein," a good climate, plenty of timber, fine scenery and other factors, which, in a prospectus, are requisite to the making of a good mine. In my Bendigo paper† I have already suggested that the vicinity of eruptive rocks need not necessarily indicate that they were the source of the metals but that their extrusion afforded the heat which made the underground waters active. I would add that the contraction, due to cooling, following the extrusion of a sheet or a mass of igneous rock

* Reference is intended particularly to the metals. † *Trans.*, xxii., 289.

may have afforded a line of least resistance or—as Prof. Posepny would put it—"a line of maximum circulation."

In closing I would express the indebtedness which we must all feel to Prof. Posepny for so extensive and so valuable a contribution. In my own case I would express it as the gratitude of an apprentice to a master.

HORACE V. WINCHELL, Minneapolis, Minn. (communication to the Secretary): It is an interesting fact that the opinions here so ably advanced by Prof. Posepny were partially stated as long ago as the end of the seventeenth century. A few quotations from "An Essay towards a Natural History of the Earth," by John Woodward, will make this plain. I quote from the third edition, published in 1723, the date of the first edition being 1695.

"That there is a perpetual and incessant circulation of water in the atmosphere; it arising from the globe in the form of vapour, and falling down again in the form of rain, dew, hail and snow. That the quantity of water thus rising and falling is equal; as much returning back in rain, etc., to the whole terraqueous globe, as was exhaled from its vapours. That tho' the quantity of water thus rising and falling be certain and constant as to the whole, yet it varies in the several parts of the globe; by reason that the vapours float in the atmosphere, sailing in clouds from place to place, and are not restored down again in a perpendicular upon the same precise tract of land, or sea, or both together, from which originaly they arose, but any other indifferently" (pp. 132, 133).

As to the cause of the circulation of waters beneath the surface of the earth he speaks as follows:

"That there is a nearly uniform fire or heat disseminated throughout the body of the earth, and especially the interior parts of it; the bottoms of the deeper mines being very sultry and the stone and ores there very sensibly hot, even in winter, and the colder seasons. That 'tis this heat which evaporates and elevates the water of the Abyss, buoying it up indifferently on every side, and towards all parts of the surface of the globe; pervading not only the fissures and intervalls of the strata, but the very bodyes of the strata themselves, permeating the interstices of the sand, earth or other matter whereof they consist, yea even the most firm and dense marble and sandstone. . . . That this vapour proceeds up directly towards the surface of the globe on all sides, and as near as possible, in right lines, unless impeded and diverted by the interposition of strata of marble, the denser sort of stone, or other like matter, which is so close and compact that it can admit it only in smaller quantity, and this very slowly and leisurely.

"That where the vapour is thus intercepted in its passage, and cannot penetrate the stratum diametricaly, some of it glides along the lower surface of it, permeating the horizontal intervall which is betwixt the said dense stratum and that which lies underneath it. The rest passes the interstices of the mass of the subjacent strata, whether they be of laxer stone, or of marle, or the like, with a direction parallel to the site of those strata, 'till it arrives at their perpendicular intervalls" (pp. 136, 137).

Woodward entertained the idea that "the whole terrestrial globe was taken all to pieces and dissolved at the deluge,"

"That at length all this metallick and mineral matter, both that which continued asunder, and in single corpuscles, and that which was amassed and concreted into nodules, subsided down to the bottom; at the same time that did the shells, teeth, and other like bodyes: as also the sand, cole, marle, and other matter whereof the strata of sand-stone, cole, marle, and the rest are for the most part composed; and so were included in, and lodged amongst, that matter. . . . And the case of metalls and minerals being the same, 'tis for that reason that in some places we now get iron, or vitriol, but no copper or alum: in others we find these, but not those: and in others both these and those, and perhaps many more. . . . Thus we sometimes see whole strata compiled of metallick and mineral nodules: others of pebles, and of flints, without the interposition of other matter. . . . Thus likewise we find strata consisting almost entirely of common salt: others of ochre: and others of several metalls and minerals, tin, lead, vitriol, nitre, and sulphur promiscuously, without any considerable mixture of coarser terrestrial matter."

Of the origin of veins he speaks in these words:

"That the metallick and mineral matter, which is now found in the *perpendicular intervalls* of the strata, was all of it originaly, and at the time of the deluge, lodged in the bodyes of those strata; being interspersed or scatter'd in single corpuscles, amongst the sand, or other matter whereof the said strata mainly consist. That it was *educed thence* and *transmitted into these intervalls*, since that time; the intervalls themselves not existing till after the strata were formed, and the metallick and mineral matter was actualy lodged in them; they being only breaches of the strata, and not made till the very conclusion of the catastrophe, the water thereupon immediately withdrawing again from off the earth.

"That the water, which ascends up out of the Abyss, on all sides of the globe, towards the surface of the earth, incessantly pervading the pores of the strata, I mean the interstices of the sand or other matter whereof they consist, detaches and bears along with it all such metallick, mineral, and other corpuscles which lye loose in its way, and are withal so small as to be able to pass those interstices; forcing them along with it into the perpendicular intervalls; to which it naturally directs its course, as finding there a ready exit and discharge, being partly exhaled thence up into the atmosphere, and partly flowing forth upon the surface of the earth, and forming springs and rivers.

"That the water which falls upon the surface of the earth in rain, bears also some, tho' a lesser, share in this action; this, soaking into the strata which lye near the surface, straining through the pores of them, and advancing on towards their perpendicular intervalls, bears thither along with it all such moveable matter as occurs in those pores in much the same manner as does the water which arises out of the Abyss with only this difference, that this passes and pervades none but the superficial and uppermost strata, whereas the other permeates also those which lye lower and deeper. (*The vadose and deep underground circulations of Posepny.*) . . .

"That therefore the metalls and minerals which are lodged in the perpendicular intervalls of the strata do still grow [to speak in the mineralogists' phrase], or receive additional increase from the corpuscles which are yet daily borne along with the water into them. Nay they have grown in like manner ever since the time of

the Deluge, in all such places where those intervalls are not already so filled that they cannot receive any more: or where the stock of metallick and mineral corpuscles, originally lodged in the strata, is not quite exhausted, and all borne thither already. . . .

"That the metallick and mineral matter which lyes in the bodyes of the strata does not grow, . . . but on the contrary, hath been diminished and lessened by so much as hath been conveyed into their perpendicular intervalls, and as hath been brought forth upon the surface of the earth by springs, rivers, and exhalations from the Abyss, since that time. That notwithstanding there have and do still happen, transitions and removes of it, in the solid strata, from one part of the same stratum to another part of it, occasion'd by the motion of the vapour towards the perpendicular intervalls of these: and in the laxer strata, such as sand, clay, and the like, *from the lower ones to those which lye above them*, and even to the very surface of the earth" (pp. 208–216).

Although the paragraphs quoted lead us to infer that Woodward thought veins were filled by the mechanical transportation of matter in small grains, yet there are in other places indications that he also had an idea of their formation by the deposition of minerals from solution. Thus, nearly a century before Werner and Hutton, were expressed ideas which were the results of long and careful observation and study which, though tinged with the theological and so-called philosophical doctrines of the day, were yet true to nature and of universal application, and which strike us as extremely valuable and original when put in modern logic and phraseology.

JOHN A. CHURCH, New York City (communication to the Secretary): I cannot agree with all the *dicta* of Prof. Posepny's valuable paper. He says (page 209, and see page 264) that in fissures "only the places remaining open would permit an active circulation of solutions and a regular deposition from them." The idea of deposition in a free space runs through the whole of the paper and is applied not only to the ore-deposits of the vadose circulation but with equal uniformity to those of the deep circulation. Such ideas seem to me to be incompatible with the crushing pressure which all agree must be found at depths of 10,000 and 15,000 feet. We have in metasomatic replacement an explanation of ore-formation which accords so well with the conditions supposable at great depth that it seems unnecessary to add to it a requirement that is certainly contradicted by those conditions.

I believe I was the first in this country to ascribe the formation of an important vein (the Comstock) to metasomatic alteration, which I then called "substitution," the term metasomasis being suggested in the same year. The character of the Comstock ore forbids the supposition of deposition in an open space; for it is not

quartz but a mixture of quartz and fragments of the wall-rock. In the opinion of experienced men more than half of the rich ore mined from the heart of the great ore-bodies was "porphyry," and at least the proportion was great. My conclusion was disputed by Mr. Becker; but one of the surest advances which vein-geology has made in the last fifteen years has been the steady growth of the idea that the thickest ore-bodies may have been formed by the replacement of masses of wall-rock fragments, or by the spread of siliceous replacement from a narrow crevice through the walls.

In deep-seated formations this method of deposition is necessarily supposed; for there are not only no open spaces there, but the situation is not even what I conceived it to have been in the Comstock. Nearer the surface there might be partings which, though minute, would be real openings, while at great depth such partings must be so closely appressed as to be no more than mere breaks of continuity.

The tendency of opinion in this country is toward metasomasis acting upon masses of crushed rock in crevices which they completely fill; and I find nothing in Prof. Posepny's paper which need cause a retreat from this view.

Prof. Posepny appears to place great reliance upon the appearance of the ore and the walls enclosing it and I suppose it is because deep-seated deposits in limestone have some strong resemblances to those of the upper circulation, that he concludes that the former must be laid down in "spaces of dissolution," like some of the latter. To me these facts point rather to an identity of active agent than to identical circumstances of its action. To make my meaning clearer I will recall some well-known facts and theories.

We know that the limestone rocks, in proportion to their amount, carry more ore-bodies than the siliceous rocks, though the latter have actually the greater number. The suitability of limestone for the deposit of ores is usually made to depend upon its solubility in water charged with carbonic acid, which is supposed to be derived from the soil by descending waters. It is carried into the interior of the earth and again discharged, for the earth being a closed vessel already full of water into which a new supply is constantly poured, it is clear that as much must be discharged into the atmosphere by springs as the atmosphere supplies by rain. I find fault with the usual view upon this subject, which apparently assumes that the deep waters must be highly charged with CO_2 derived from the surface. On the contrary it seems to me that the discharging water must bring out as much CO_2 as it takes in, for neither water nor gas can

be lessened in quantity except by the comparatively small amount that enters into fixed combinations in the rocks. Since the solubility of gas in water is increased by pressure we must suppose that the dissolved CO_2 remains with the water that absorbed it throughout the whole range of circulation and that there cannot be any discharge of surface CO_2 in the interior. Yet we know that large quantities of CO_2 are discharged from the earth as gas not dissolved in water, besides that which is dissolved; and this gaseous discharge must be in excess of the CO_2 carried in. May we not find the source of this excess in deep-seated metasomatic replacement?

The operation of solutions whose composition we do not know can be judged only by their effects. When metasomatic replacement takes place in limestone it is generally assumed that lime carbonate goes into solution, while its place is taken by the ore-substances, that is to say, that the action is molecular substitution and not atomic; but it is conceivable that the change should begin by an interchange of acidic elements—that SiO_2 should drive out CO_2. Subsequent changes might remove the lime silicate by another process of substitution, since it is more soluble than silica; but the point is that CO_2 would be liberated, and though the original ore-solution were free from CO_2, it would immediately become charged with that agent and exert the well-known dissolving power of carbonic acid solutions. In this way a solution which would have but feeble power in other rocks may in limestone set up a chain of reactions that would intensify its effects. These considerations lead to interesting conclusions.

We have a source of CO_2 in rocks, however deep-seated, and consequently effects may be produced at any depth, which simulate those of surface-waters, though probably without the production of caverns. Since the mode of solution is the same, the appearance of the walls lining an ore-body and the appearance of the ore itself may be almost precisely the same as in the vadose region.

Limestone contains the elements for self-destruction, since the breaking up of one lime-carbonate molecule may cause the solution of another; and, as this cannot be said of any other rock, we reach a possible explanation of the comparative frequency of ore-bodies in limestone. The dolomites would, of course, present similar reactions.

There are two questions which are distinguished, even in the difficult study of veins, by the obscurity which hangs over them. One is the selection of a favored stratum for ore-deposition. In

some situations the solutions, before reaching the stratum of actual ore-deposition, must have passed several strata suitable for their action, if they had possessed from the beginning the power of solution which they showed ultimately. I believe this objection has been urged against the lateral-secretion theory as applied to Leadville. Ore-solutions exhibit a selective power which is extraordinary in a water fully supplied with dissolving qualities, but quite explicable in a solution which lacks this power. I suppose it is impossible at present to determine why the rocks now exposed at Leadville were selected for attack by the solutions; but I think it is comprehensible why that action, however extensive, should be localized by the development and action of CO_2 in the neighborhood where it began.

An obvious consequence of these considerations is that the aqueous circulation of the earth becomes, through the medium of metasomasis, a means for restoring to the atmosphere accumulations of carbon that represent the organic life of past times.

The second obscure question is logically one which ought to be answered before we discuss the origin of ores at all. It is the secondary alteration of already-formed ore-deposits. I have no doubt that some of the deep-seated deposits which we see are actually a product of the vadose circulation. Formed ten thousand feet below, they have been raised until they are now ten thousand feet above the sea-level, and, during the immense period through which they have been subjected to the surface circulation, they have not only been re-arranged but may have actually lost their ancient origin. Even the rock in which they were deposited may have been removed and the ore transferred to another member of the series. Structural facts may prove deep-seated deposition, but actually the ore-bodies we see are often in whole or in part hysteromorphs. This is especially true in limestone deposits. Though these facts are well-known, they do not exert the controlling influence upon opinion which I think they deserve, probably because of the extreme difficulty of separating the primary from the secondary phenomena. No writer that I have seen has given to this subject half the importance which a mining engineer must give it.

I cannot agree with the author in giving so much importance to crustification, as he describes it. Certainly a banded structure can arise from the replacement of fragments arranged in layers by pressure and friction, as well as in many other ways, and does not prove deposition in a cavity, whether filled by water or air. He has mis-

understood me in saying that I found crusts of quartz alternating with calcite in the Justice mine (Comstock). I said the thick masses of calcite in that mine rested on a thin layer—an inch or two—of quartz; but this is not crustification in the author's sense. My view of that occurrence was that an insignificant quartz seam, probably belonging to the last period of the Comstock, was first produced, and that the calcite was formed by replacement of the wall-rock at a later period. There is not the least evidence of deposition in a cavity. If there is crustification, that appearance does not have the significance which our author gives to it.

I have not attempted to particularize the many points in which I find myself in agreement with the author; and since my remarks have been rather in criticism, I desire to express in conclusion my high appreciation of his admirable treatise.

S. F. EMMONS, Washington, D. C. (communication to the Secretary): Prof. Posepny's paper, or treatise, as it rather deserves to be called, is a most important contribution to the theory of ore-deposits. His wide personal observation of most of the important mines in so many different parts of the world and his critical acumen as an observer, combined with his long continued studies of the subject, give to his words an exceptional authority. Whatever might be said, therefore, in praise of his article (and it would take much time to say it all) would hardly add to its value. But the very high quality of his work renders any errors in it exceptionally hurtful, and I shall therefore confine my remarks mainly to what seem to me to be erroneous teachings, and to points in which I differ with him either wholly or in part. I would first say, however, that to the greater part of the views put forth in this paper I most heartily subscribe, especially to those on underground circulation, and on the great rarity of ore-deposits which have been formed contemporaneously with the enclosing rocks.

It is well known that for some years past there has been a very warm discussion between Posepny and Stelzner on the one side, and Sandberger on the other, in regard to the derivation of the material of ore-deposits, the former holding to the ascension, the latter to the lateral-secretion theory. Without attempting to determine the merits of either side of the controversy, which it would be unwise to do without examining personally the deposits in question and their geological surrounding, one is inclined to believe that the views of either of such able geologists must have scientific value, whether one or the other may be proved to be erroneous in a particular instance.

I regret, however, to see this controversy brought into what should be a broad and impartial discussion of the facts of nature, and to detect in certain cases what appears to be a tendency on the part of Prof. Posepny to adopt a rather forced construction of these facts, in order to make them support his views rather than those of Sandberger.

The lateral-secretion theory, which Posepny ascribes to Sandberger, is much narrower than that which I, and I think most American geologists, hold. It confines the derivation of the vein-contents to the wall-rock in immediate contact with the deposit; whereas, in my view, a derivation from rocks within reasonable proximity, as opposed to a source at unknown depths ("in the barysphere"), would constitute lateral-secretion, and ore-bearing currents may in such cases have had an upward, downward, or lateral motion according to differing local conditions of rock-structure. Prof. Posepny himself admits, in his admirable discussion of vadose or shallow and deep underground circulation, the possibilities of such lateral-secretion when he describes the latter (p. 26) in the following words:

"The ground-water descends in the deep regions also through the capillaries of the rocks; at a certain depth it probably moves laterally towards open conduits, and reaching these, it ascends through them to the surface."

The distinction between the action of surface and that of deep-seated waters is an important one in the study of ore-deposition; but I do not think that Prof. Posepny is justified in assuming, as he does, that only ascending waters are capable of depositing ores. Futhermore, the necessary derivation of metallic minerals by these ascending waters from the "barysphere" seems too far-fetched. At what depth the barysphere will be found, meaning thereby the part of the earth's interior where the rocks have a much higher specific gravity than those that come under our observation, is purely a speculative question; but as our surface observations extend over a thickness in round numbers of about 100,000 feet of rocks, and show no appreciable difference of specific gravity between the deeper and more shallow rocks, except such as is due rather to different degrees of density than to heavier mineral constituents, it seems safe to assume that such a barysphere must exist, if at all, at such great depths as to be beyond the reach of any mineral-bearing waters. If such a zone rich in heavy metals exists in depth, as there is some reason to believe, my own view, as expressed in my paper read at this meeting, is that the heavy metals which constitute the ore-

deposits were brought up from it into the outer crust of the earth by the various eruptive rocks, and were partially concentrated in certain parts of these eruptive rocks, by differentiation during the process of cooling. In this view I agree with Vogt, whom Prof. Posepny mentions (p. 330) in a somewhat slighting manner. I differ with Vogt, however, in that I consider the greater part of our ore-deposits, all certainly that have come under my limited observation, to be due to further concentration, perhaps many times repeated, both chemical and mechanical; and I am entirely at one with Prof. Posepny in considering their final concentration into their present form to be due to the action of circulating waters.

Prof. Posepny's belief in the capabilities of an ascending current of heated waters or thermal springs seems to me, in some instances, as exaggerated and unreasonable as his rendering makes Sandberger's disbelief, in the instances he cites. He quotes a single observation by Nöggerath in 1845 on the finding of vertical channels in limestone 8 to 35 inches in diameter, near Aachen, which are supposed to have been eaten out by the ascending spring-waters, and from this draws the wide-reaching conclusion that ascending waters may actually force their way up through rock masses without the necessity of pre-existing cracks or channels. Among instances where he uses this explanation to account for the formation of an ore-deposit the most remarkable is that of Laurium (p. 320) where the ore-deposits as shown by the diagrammatic section (Fig. 87) are funnel-shaped bodies extending outward from the contact of flat-lying schists into subjacent and superjacent limestones, that is both upwards and downwards. My own explanation of this section, deduced by observations in limestone-deposits in this country, would be that the ore-bearing currents circulating along the contact-planes had eaten outward into the more soluble rock, upwards from the upper contact, and downwards from the lower contact. But Prof. Posepny explains the funnel-shape of the ore-bodies on the upper contact as produced "by the pressure of the ascending solutions." The lower contact he offers no explanation for, but says "it is perhaps somewhat ideally sketched."

It is unprofitable, however, to discuss deposits which neither of us have seen; for nothing is so liable to misconception as the description of ore-deposits one has not seen by a person with whose qualifications and accuracy of observations one is not familiar. This is shown in Prof. Posepny's remarks upon the Leadville deposits, in which he concludes that I must acknowledge that my views in regard to the

downward course of the ore-bearing solutions were incorrect, because several mining engineers have shown them to be untenable. It does not seem to occur to him that the views of a mining engineer (who is not necessarily a geologist) based upon studies of a single mine or set of mines would be of less value as applied to such theoretical questions than those of a trained geologist who had made a study of all the geological conditions and mines of a district. Of the three articles quoted by him, that of Mr. Freeland offers no opinion upon the subject in question. Both this and Mr. Rolker's article were written before my monograph was published, otherwise Mr. Rolker would have found his objections on these points foreseen and accounted for there (p. 490).

In the summer of 1890, I spent nearly two months at Leadville studying the recent developments with the special purpose of testing the correctness of my former deductions, and Mr. Blow accompanied me through the workings of North Iron Hill with which he is so familiar. While I naturally found many details of geological structure which were not, and could not have been, correctly represented on the underground sections accompanying my report, I found no reason to change my views of the manner of formation of the ore-deposits, and I convinced myself (and I think Mr. Blow also) that his objections were based on a misapprehension of certain geological phenomena. It were too long to give here all the results of my observations, which I regret that circumstances beyond my control have as yet prevented me from publishing. I will say, however, as bearing upon this point, that in no case did I find any convincing evidence of the action of ascending solutions. The ore-bodies occur in two general forms, either on the approximately horizontal contact-planes of porphyry and limestone, or along nearly vertical fissures crossing the limestone beds. In either case, wherever the form of the ore-body was such as to throw any light upon the probable direction of the ore-forming currents, it showed that they must have descended, for they all terminated more or less in a point or wedged out downwards.

Before discussing this further, it may be well to repeat my statement given in the monograph (p. 379) which has evidently been overlooked or misapprehended by my critics. I say, with regard to the *immediate* source of the ores:

"1. That they came from above. 2. That they were derived mainly from the neighboring eruptive rocks.

"By these statements it is not intended to deny the possibility that the materials

may originally have come from great depths, nor to maintain that they were necessarily derived entirely from eruptive rocks at present immediately in contact with the deposits."

I do not maintain, as many have assumed, that the ore was derived from the white porphyry. I do not pretend to be able to determine what particular body of porphyry it came from. The objection of Mr. Blow that it could not have come from the white porphyry because this is not all decomposed (*not*, "not at all decomposed," as Prof. Posepny puts it), is based upon a misapprehension of what constitutes decomposition. If Prof. Posepny will read the description of the eruptive rocks in my chapter on rock-formations, he will see that all the Leadville porphyries are more or less decomposed within this district; when Mr. Cross and I were making our geological studies we had to go several miles away before we could find a specimen of unaltered white porphyry for microscopical study.

My contention with regard to the ores of this district, as opposed to the theoretical views of Prof. Posepny and those of his school, would not have been essentially affected, however, if it had been shown that the solutions had ascended to reach the *locus* of the present deposits. The fissures across the limestone which gave access to the solutions forming the ore-shoots of North Iron Hill described by Mr. Blow are, as I showed in my monograph, faults with only a few feet of displacement, and can extend to only limited depth; in some cases their lower limit could be detected. The great faults which extend several thousand feet in depth are not ore-bearing, except in so far as ore has been dragged into them in the movement of their walls, one upon the other. But the extent in depth, even of these great faults, must be extremely limited as compared with the distance of the barysphere. I believe that the eruptive rocks originally brought up the heavy metals from the depths into the general region in which the ores are now found. Some of these eruptives still contain over four per cent. of them, in spite of all the leaching to which they have been exposed. The ore-deposits are concentrations of these materials by deep underground waters, flowing along natural channels, and depositing along those which admitted a comparatively free flow, as compared with a capillary circulation. Such a flow may have been upward, downward or lateral, according to varying structural conditions. The ascending solutions which Prof. Posepny contemplates, however, could not have formed ore-bodies of the form of those found in Leadville; and

it was for that reason that I laid stress upon the evidence of their probable downward course.

As regards the phenomena of "crustification," I may not have been explicit enough in stating its absence. In my original examination I searched in vain for any evidence of it. In my second examination, almost entirely in bodies of unaltered sulphides, I found overwhelming evidence that the ore was not deposited in pre-existing cavities, but by metasomatic replacement of the limestone. In the great bodies of the A. Y., Minnie and adjoining mines not only could every detail of the granular structure, joints and cleavage of the original limestone be detected at times in the sulphide ore, but even the cracks in the top of the ore-body through which the ore-bearing solutions had descended were often visible. In abandoned drifts, where the limestone dust had accumulated on the walls, one would have supposed the walls to be all limestone until the breaking off of a fresh fragment by the hammer showed the metallic gleam beneath.

G. F. BECKER, Washington, D. C. (communication to the President from Newport, R. I.): The paper of Prof. Posepny is a very valuable contribution to the science of ore-deposits, and deserves a more careful critical discussion than I am able to assist in giving to it at this time, in the absence of facilities for reference to authorities, etc. A few general observations, therefore, must suffice at present to indicate my views.

The theory of the substitution of ore for rock is to be accepted only when there is definite evidence of pseudomorphic, molecular replacement. Prof. Posepny is very clear on this point (p. 208), and I have insisted upon it in my memoir on quicksilver-deposits and in a paper on quicksilver about to be distributed. Prof. Posepny appears to me, on the other hand, to lay too much weight upon the structure which he calls "crustification," as indicating exclusively the filling of open cavities and the absence of replacement. Metamorphic processes are very frequently accompanied by the formation of layers similar to stratification and crustification, and, indeed, from similar causes. Strata are distinguishable only because the circumstances of deposition undergo more or less marked variations, and the banded structure of agate or hematite is also due to variations in conditions of deposition such as the strength of the solutions, or the rapidity of their flow, or temporary changes in the composition of the fluid. It appears to me that the banded structure attending metamorphism, as a matter of observation in many cases,

is due to entirely similar causes. Thus a mass of iron immersed in a copper-solution will precipitate the copper as a laminated mass, unless great precautions are taken to secure uniformity of temperature, etc. In short, lamination is an ordinary attendant of processes of deposition, whether by replacement or otherwise, whenever they are so slow as to be subject to changes of condition. Hence crustification seems to me an insufficient guide to genetic diagnosis.

The indications of replacement which I should rely upon are twofold: crystalline pseudomorphosis and the irregular enlargement of fissures in the replaced mass. Of the latter, Prof. Posepny gives a good illustration (Fig. 85). As for pseudomorphosis, it has a very important bearing on the work of Mr. Emmons and of J. S. Curtis, for it appears to be thoroughly well established that galena forms pseudomorphs after calcite; and, therefore, the theory of replacement of limestone which they advocate is to say the least possible. The studies of these observers at Leadville and Eureka tend to show that replacement has been the chief process; but so far as I can recall their remarks they do not assert the entire absence of deposition in pre-existing openings; so that even if crustification were an infallible sign of filling, the detection of crusts (Posepny, p. 300) would not invalidate their position. Another objection to Mr. Emmons's views is expressed by Prof. Posepny in the sentence (p. 295), "It is difficult to believe that metasomatic processes could produce such pronounced ore-shoots as those described at Leadville." I cannot share this view, for replacement, like solution, must occur along fissures or channels, and metasomatic ore-bodies will present analogies in form to the open spaces of caves of solution.

It seems substantially certain that open cavities in limestones can form only above the permanent water-level of a country, since in such a country the water below this level must be approximately saturated with calcium carbonate. On the other hand, replacement may take place at any depth. Now, in the Great Basin, the Tertiary and Early Quaternary were very wet periods, and if the Eureka limestones have been excavated by surface waters, the excavation and subsequent ore-deposition, according to Prof. Posepny's view, must be crowded into the late Quaternary. The present precipitation of that region would seem insufficient to bring about much cave-formation, while a greater precipitation would raise the water-level. Thus, so far as Eureka goes, the hypothesis of subsequent filling raises distinct, though perhaps not insuperable, difficulties as to the formation of the cavities.

The foregoing notes should be reinforced by examples and citations which I cannot now furnish.

F. M. F. CAZIN, Hoboken, N. J.: If I venture to add a few lines to Prof. F. Posepny's treatise on the genesis of ore-deposits, my justification is derived from practical work done and consequent opportunities enjoyed in a region, to which the learned author personally has remained a stranger, and of which in existing literature no such account is available, as would afford to him the powerful argument in favor of his theories really presented by the region itself, to a degree of importance beyond any other mentioned by him.

The region to which I refer furnishes a demonstration of the xenogenous origin of ore-deposits, heretofore considered as idiogenous, which I may properly call gigantic, and which is equalled nowhere on the face of the earth, as far as known. I refer to the region so tersely described by James Douglas (*Trans.*, xix., 694), in these words:

"In the Appalachian chain from Vermont to Georgia, there are imbedded in the crystalline schists large masses of pyrites, some consisting of ordinary bisulphide of iron but most of them of pyrrhotite, and all carrying more or less copper."

There is, on the long stretch from Vermont (Mr. Douglas might have truly said "from Canada and Maine") to Georgia, no older mine, and none with more important development on the ore-deposits thus described, than that which has been called by State-legislative act "the Vermont Copper Mine." Its history began before the world knew about copper on the shore of Lake Superior. For many years it produced at the rate of 3,500,000 pounds of copper per annum, and, with adequate improvements, could do so to-day. I have seen its developments on a deposit dipping 24° N.E. to a distance of 2350 feet from the surface, and to a vertical depth below sea-level of several hundred feet, the lateral expansion of stopes ranging between 50 and 350 feet. Having been connected with this mine from early in 1882 to June of 1888, I have had opportunity to search for the origin of the ore-body there exploited.

Having discovered unmistakable local evidence as to the true nature of such origin, it remained to ascertain the identity or uniformity of effect from identical causes on other deposits falling under the description above quoted; and it was not difficult to establish such identity and harmony.

At a distance of ten miles in a northerly direction another mine in the same geological position, at Corinth, offered evidence leading

to the same conclusions, and in a southern direction at a distance of four miles, the Strafford mines, and at a further distance of sixteen miles the Pompanoosuc mine, all similarly situated, demonstrated the same effects under similar causes. And a visit to many other localities within the Huronian Appalachian region could confirm only the conclusions, to which the observations in the Vermont mine had been leading me.

Except as to dip, topography and shape of workings, Fig. 56 in Prof. Posepny's paper might well serve as the image of the Vermont ore-deposit, represented on a vertical plane along its dip. And Figs. 54 and 55 may well serve as a representation of horizontal and vertical planes, as they are seen inside and outside of the Vermont, Corinth and Strafford mines, where the designs shown in these figures not only occur in dimensions varying from a few fathoms to many hundreds of fathoms, but also in varying material. In the mine, this consists of the sulphides of iron and copper, and outside and at distant points therefrom, in an admixture of carbon-matter (graphite) in the country-rock. This rock is a micaceous schist, the graphitic part varying in proportion from a mere trace to 100 per cent., becoming marketable plumbago in many localities, though without sufficient extent, as a rule, for exploitation.

But it is not on the similarity of design between sulphide and carbon admixtures in the rock alone, that my conclusions were built, as a description of the mine will further show.

In their lateral expansion the ore-stopes in the Vermont mine present a figure very similar to the one presented in Prof. Posepny's Fig. 93, if the longitudinal extent be assumed as 2350 feet, with the lower part broadened. But similar figurations are also presented on a smaller scale, where in quarries the rock is laid bare on one of its dark seams.

The roof and floor of the Vermont ore-deposits are virtually impenetrable to water; the mine at 1000 feet vertical depth being dry. But there is uncovered at a distance of a few hundred feet from the outcrop an almost vertical cross-fissure or fault (without perceptible faulting), filled with calcareous spar containing sparsely distributed small seams of galena, which cross-fissure allows a few hundred gallons of water a day to percolate into the workings. Some of this water finds its exit through an abandoned adit. Where it reaches the surface, and where its flow is slow, allowing evaporation, it deposits a slime of virgin-white carbonate of lime; and as it passes down into the valley, it deposits for miles a mixture of carbonates of

lime and iron, giving to the creek-beds their peculiar coating of color, as a result of atmospheric reduction of the iron carbonate.

The ore of the Vermont in its mineral character has one main peculiarity, which is common to the deposits as described from Canada to Virginia and Georgia, namely, that quantitative analysis shows neither the figures required to constitute the one of its components as ferro-sulphide, nor those required to show it as ferri-sulphide, these figures varying all the way between those applying to FeS and those applying to FeS_2.

The structure of the ore is the same as that of the graphitic rock, with the same variations in the ore as to contents in sulphides, as there are in the country-rock as to contents in carbon-matter. That in no case I have met with a nucleus of carbon in a body of sulphides, I have attributed to a full completion of the metamorphosis.

Yet another feature is common to the ores of the described deposits. For a long distance on the northern part of these continental deposits, wherever they occur in the Huronian schists, their ores carry nickel in proportions varying from a mere trace in the copper-metal made therefrom to an available percentage in the ore itself.

Although much disinclined to draw generalizing conclusions from isolated geognostic phenomena, I claim justification in the case at hand for the following conclusions, because the evidence is such as repeats itself on a large area, and once understood presses itself upon our attention, so as to be no longer ignored:

1. The iron and copper sulphides occurring in the Huronian crystalline schists on the eastern part of the North American continent have locally displaced carbonaceous matter, where faulting of strata aided water-circulation, such water containing sulphate salts of the metals in solution.

2. The metamorphic action of absorbing mineral carbon and of setting free CO_2 is continuous to the present day.

3. The product of such action extending below sea-level being observable in lines nearly parallel with the coast-line of an entire continent, and showing equal peculiarities in composition on the entire line, it is reasonable to assume oceanic action.

It is true that the ocean of our period evinces the presence of copper only by its presence in maritime organisms. But when, on the shores of a once existing Triassic sea we find embedded in massive but porous sand-rock an entire palm-vegetation, that has turned into copper-glance, as my eyes have seen it (compare p. 316 of

Prof. Posepny's paper), then we may well assume the presence of a perceptible quantity of copper in a Triassic sea, though not necessarily sufficient to destroy animal life. It is even a matter of time only for an ocean like the one of our own period to provide Pecillopora and Heteropora corals with their copper, or to be the means of metamorphosis of carbon-deposits into copper-sulphides in part; the percentage of copper in these deposits being in general not above three per cent, of the deposits as a whole.

I find a further justification for stating these facts and the conclusions to which they lead in the circumstance, that the learned author, although mentioning the occurrence of graphite in crystalline schists, does not mention that this graphite anywhere accounts for the origin of ore-beds.

The description of the Sudbury ore-beds deals with a case far more complicated than those considered by me, because there Huronian strata similar to those met at the different mines in the Appalachians, have been disturbed by more recent dioritic eruptions, which subjected the pre-existing ore-beds to a new partial or second metamorphosis, by which the true state of affairs is very materially obscured, misleading the describers into the untenable assumptions, so justly controverted by the learned author. Had he been informed of the facts, as I have described them above, the author of this eminently interesting and progressive essay on the genesis of ore-deposits would have been able to knock the last crutch from under the theory of an eruptive origin of the ore-deposits at Sudbury and elsewhere in the crystalline rocks of the Huronian period.

I take this opportunity to furnish, on another point, information for which Prof. Posepny apparently calls (p. 317).

A few months only after my report on the Nacimiento copper-occurrence was published, with the consent of those interested, in the *Engineering and Mining Journal*, Aug. 7 and 14, 1880, the United States surveyors, who were commissioned by the Surveyor-General of New Mexico to survey the twenty-one mining claims described by me, were driven off these claims by a numerous band of jumpers, who had swarmed into those parts as the usual *avant-garde*, indicating, as stormbirds the storm, the approach of a new railroad line in those remote parts. To reinstate the legitimate owners either brutal force or litigation had to be employed. The ill-success of other copper-enterprises in New Mexico, though quite foreign to all natural conditions, caused them to resort to neither. When, in 1891, I

again visited the upper Rio Grande valley, I found on the platform of the railroad-station at Bernalillo, N. M., about a car-load of the precise cuprified palm-vegetation formerly described by me, showing that there had survived some activity at Nacimiento; but, as stated in my first report, profitable operations are possible only on a scale like that on which lead is obtained from a similar sand-rock at Mechernich in Rhenish Prussia.

THE PHYSICS OF STEEL.

Discussion.

[The following discussion, comprising both remarks made at the Chicago meeting and contributions since forwarded to the Secretary, is based upon the following papers, presented at that meeting:

"Segregation and its Consequences in Ingots of Steel and Iron," by Alexandre Pourcel, Paris, France. (See p. 105, *Trans.* xxii.)

"Microscopic Metallography," by F. Osmond, Paris, France. (See p. 243, *Trans.* xxii.)

"Microstructure of Ingot-Iron in Cast Ingots," by Prof. A. Martens, Berlin, Germany. (See p. 37.)

"Microstructure of Steel," by Albert Sauveur, South Chicago, Ill. (See p. 546, *Trans.* xxii.)

"Further Observations on the Relations Between the Chemical Constitution and Physical Character of Steel," by William R. Webster, Philadelphia, Pa. (See p. 113.)

"The Heat-treatment of Steel," by H. M. Howe, Boston, Mass. (See p. 466.)

Since all these papers were considered together, no attempt has been made to separate the discussion strictly under the several heads.]

William R. Webster, Philadelphia, Pa.: I desire to say that in my first paper (*Trans.*, xxi., 766) the actual ultimates were subtracted from the estimated ultimates, whereas in the paper submitted at this meeting the estimated ultimates are subtracted from the actual, thus giving contrary signs. The latter method corresponds with the direct effect of low and high finishing-temperatures; that is, a plus difference indicates low, and a minus difference high, finishing-temperature. I make this explanation to prevent confusion in comparing the two papers.

Mr. Sauveur has shown that there is a close relation between the size of the grain and the ultimate strength, and also that the size of the grain depends on the temperature at which the material is finished in rolling, and on the chemical composition of the steel. I have shown that there is a close relation between the chemical

composition of the steel and its ultimate strength, and also that the temperature at which the material is finished affects its ultimate strength. If the differences due to variations in the finishing-temperature could be eliminated, I have no doubt that a close relation would be found to exist between the ultimate strengths as given in my table of chemistry of material, and the size of the grain as given for the different ultimate strengths in the table of Mr. Sauveur.

In order to carry out an investigation of this kind, it would be necessary to have the plates heated and rolled under personal supervision in order to control the finishing-temperature. I would be willing to co-operate with Mr. Sauveur in an investigation of this kind, of say 200 plates, if he cares to undertake the microscopic part of the work.

It would be a hard matter to estimate the amount of steel that is spoiled daily by being finished at too high a temperature, or to put into practice a method of overcoming this difficulty. The rollers and heaters are *tonnage-men*, and they will not always hold the material back in order to finish it at the proper temperature.

The following are my corrections of the ultimate strength for thickness and width of plate. These corrections are made necessary only by the effect of thickness and width on the finishing-temperature in ordinary practice:

Corrections for Size of Plates.

Plates. Inches thick.	Up to 70 inches wide. Lbs.	Over 70 inches wide. Lbs.
$\frac{3}{4}$ and over,	— 2000	— 1000
$\frac{11}{16}$ "	— 1750	— 750
$\frac{5}{8}$ "	— 1500	— 500
$\frac{9}{16}$ "	— 1250	— 250
$\frac{1}{2}$ "	— 1000	— 0
$\frac{7}{16}$ "	— 500	± 500
$\frac{3}{8}$ "	0	+ 1000
$\frac{5}{16}$ "	+ 3000	+ 5000

On applying the corrections to the 408 tests given in my paper, we have for both mills:

				Per cent.
Per cent. within	1000 pounds	= 28.4	being a gain of	2.4
" "	2000 "	= 55.1	" "	2.9
" "	3000 "	= 74.7	" "	3.9
" "	4000 "	= 89.9	" "	5.8
" "	5000 "	= 94.9	" "	2.0

(Compare Table IV., *ante*, page 124).

These corrections for size will, no doubt, be modified from time to

time, as we acquire more skill in controlling the temperature at which the material is finished in rolling.

PROF. T. M. DROWN, Boston, Mass.: Some investigations which I have recently made in the purification of water by freezing, have given striking illustrations of segregation. It is well-known that mineral matters dissolved in water are eliminated when the water is partially frozen, and there must be a corresponding concentration of the soluble substances in the remaining water. Usually this concentration is not appreciable when the ice forms but a small portion of the whole body of water in a pond or lake; but when a shallow body of water freezes solid, it will be found that the bottom portion contains the greater part of the substances originally present in solution in the water.

In making artificial ice the conditions of cooling are very similar to those which obtain in the cooling of steel or iron, only the rate of cooling is very much slower; a can of water about 13¼ inches square, and 32 inches high, holding about 200 pounds of water, requiring about two days to become frozen.

In such a case one would expect the greatest concentration of impurities to be in the middle or upper portion of the interior core; but in the blocks which I examined, the largest amount of impurities was found in the lower portion of the interior of the blocks. This was due, doubtless, to some peculiarity in the application of the cold brine which circulated around the outside of the can.

The best instance of segregation I have noticed in an artificial ice-block was one in which a well-water had been frozen which contained 18.04 parts of mineral matter per 100,000 in solution.

The ice-block was divided into six portions, an upper, middle and lower portion of the outside, and an upper, middle and lower portion of the interior.

The analyses of the well-water and of these six portions of ice are given in Table I., on the following page.

In this connection it is interesting to note that in a case in which a sample of distilled water was frozen, the lower portion of the core had (when melted) a distinct odor of rubber hose, while the rest of the block had no odor. The cans had been originally filled by means of a rubber hose, and the slight odor thus communicated to the water was concentrated in the portion last frozen.

As bearing on the question of the relation between the degree of elimination of impurities and the rate of cooling, I might cite the results of the analysis of different layers of natural ice cut from a

TABLE I.—*Analyses of Spring-Water and Ice.*

Parts per 100,000.

	Appearance.			Odor.		Residue on Evaporation.	Ammonia.		Chlorine.	Nitrogen as		Hardness.	Oxygen consumed.	Iron.	Zinc.
	Turbidity.	Sediment.	Color.	Cold.	Hot.		Free.	Albumin-oid.		Nitrates.	Nitrites.				
Spring water, boiled and filtered, used for freezing.	None.	None.	0.0	None.	None.	18.04	.0110	.0010	3.45	.7500	.0200	4.4	.0547	.0006	.....
Block of Ice:															
Outer layer, upper third.	None.	Sl't, dark colored particles.	0.0	None.	None.	0.44	.0044	.0008	0.04	.0000	.0002	0.0	.0078	.0000	None.
Outer layer, middle third.	None.	None.	0.0	None.	None.	0.24	.0082	.0002	0.05	.0000	.0000	0.0	.0109	.0000	None.
Outer layer, lower third.	V. slight.	Cons., white.	0.0	None.	None.	4.00	.0052	.0000	0.44	.1100	.0080	1.6	.0086	.0012	.2000
Inner core, upper third.	None.	Slight, white.	0.0	None.	None.	4.48	.0102	.0000	0.72	.1800	.0130	1.4	.0255	.0000	None.
Inner core, middle third.	V. slight, white.	Cons., white.	0.0	None.	None.	14.76	.0262	.0016	3.27	1.0000	.0700	4.9	.0730	.0008	None.
Inner core, lower third.	Distinct white.	Heavy, white.	0.03	None.	Faintly earthy.	70.60 61.10	.0602	.0082	11.59	1.6000	.2800	21.0	.2993	.0045	.2400

deep pond. The water of the pond contained a considerable amount of dissolved and suspended impurities, and it will be noticed in the analyses which follow that each successive layer from above downward is purer than the one above. There could have been no difference in the conditions of freezing in these layers, except the rate; that is to say, the rate of freezing was probably slower as the ice increased in thickness.

TABLE II.—*Analyses of Pond Ice in 5 Layers. Thickness, 9 Inches.*

Parts per 100,000.

	Fixed Residue.	Free Ammonia.	Albuminoid Ammonia.		Chlorine.
			In Solution.	In Suspension.	
Top layer, with snow-ice,	1.10	.0080	.0048	.0166	.02
Second layer.....	0.50	.0034	.0012	.0056	.02
Third layer.....	0.55	.0016	.0008	.0032	.01
Fourth layer.....	.....	.0016	.0008	.0022	.00
Fifth layer.....	0.05	.0012	.0002	.0006	.00

R. A. HADFIELD, Sheffield, England: I can confirm from recent experience that, as pointed out by M. Pourcel (*Trans.*, xxii., 107), segregation may occur in other than thick sections. From a mild steel ring casting, otherwise of normal character, having a sectional area of about 7 inches wide by 2½ thick, we obtained at the Hecla Works, Sheffield, an analysis as follows:

C.	Si.	S	P.	Mn.
1.20	.....	.62	.35	.....

The drillings from which the analyses were made were taken from the center of the top portion of the sample. The presence of so large a quantity of sulphur might be partially accounted for in other ways; but the phosphorus could only be explained by the theory of segregation. M. Pourcel says he considers it to be difficult to obtain homogeneous masses of chromium and other steel-alloys. We do not find this to be the case at our works in Sheffield, where we manufacture considerable quantities of chromium-steel for armor-piercing projectiles and other purposes. We seldom get more than about 0.1 per cent. variation, which, on say a total percentage of 2 per cent. Cr., is slight. The same remark applies to our man-

ganese-steel. Fine wire, 0.5 mm. in diameter, of such steel, obtained from ingots 10 inches square, practically shows uniformity. Also in our special silicon-steel containing as much as 2½ per cent. of this metalloid, we have not noticed any signs of segregation. Segregation must not be confounded with imperfect mixing. At present there is often carelessness in the latter respect. The "physics" added to decarbonized iron are usually in small quantities, and yet steel-makers, whilst taking the utmost care in other respects, often pursue the policy of "laissez faire" in this matter. Segregation undoubtedly does occur, and is often abnormal and excessive under certain special conditions. But it seems to me that in face of the wonderful regularity of steel production nowadays, M. Pourcel goes too far in saying (page 108) that "homogeneity is a quality almost impossible to realize in a block of steel." The writer knows of classes of work in certain Sheffield trades where both Bessemer and Siemens steel are used, and in which a variation of more than 0.5 per cent. carbon would be quickly detected by the workmen. As both classes of material "fill the bill" satisfactorily, it is safe to assume that regularity and uniformity are not so unattainable as might be imagined, provided, of course, that the steel has been carefully manufactured in the first instance. I am glad to note M. Pourcel's reference to the advantage of using chromium. There is much to be done in the direction named, though it must, at the same time, be clearly borne in mind, as proved by my own experiments detailed in my Iron and Steel Institute paper, on "Alloys of Iron and Chromium," that the metal chromium does not act directly as a hardener but only through its action upon the carbon present.

With reference to Mr. Sauveur's valuable paper on the Microstructure of Steel, we steel-founders are especially interested in the development of research on the structure or, as Mr. Sauveur terms it, the "grain" of our steel. Specifications for steel castings are nowadays made severe, and in many cases we are asked to give a metal of equal or superior ductility to many brands of wrought-iron. As stated by Mr. Sauveur (*Trans.*, xxii., 550), there is no doubt that, generally speaking, the power of elongation and of reduction in area in unhardened steel depends upon the grain being kept small. Recently, however, I have noted that some of the German steel castings which have given good results in the testing-machine show an exceedingly coarse fracture. Still the same castings did not come out so well under the drop-test as other steel castings which had finer grain, though not giving so high elongation in the testing-

machine. Personally I should, if buying steel castings, prefer fine-grained steel. This usually denotes that care has been taken in the annealing process. The use of the microscope in the examination of steel must undoubtedly extend and prove of great service to the steel-maker.

President Howe has submitted a treatise of high value. In several of my own papers I have called attention to the importance of a systematic study of this question of "heat-treatment." Each year we are beginning to find that iron, whether as carbon-steel or in its other several alloys, is one of the most sensitive of metals to heat-treatment. M. Osmond and Prof. Roberts-Austen have by their valuable work opened the door to a great field of research, and one which without doubt will have to be carefully investigated by metallurgists who have to meet the increasingly severe requirements stipulated by the other branches of the engineering profession. I am glad to find that Mr. Howe still sees no reason to support the *Beta*-iron theory. Having so fully dealt with this subject in my own paper (*ante*, p. 148), I need not add anything further here. I am entirely in agreement with him on this point.

The interesting information given by Mr. Howe respecting a neutral zone of hard tool-steel when subjected to heat, ought to prove of considerable practical service. The discovery of this fact is important, and serves to explain some of the anomalies hitherto noticed in dealing with this class of material. The amount of care and attention bestowed by Mr. Howe in the carrying out of the numerous experiments detailed in his paper must have been exceedingly great. It is much to be hoped that this paper will find its way into the hands of all those interested in the heat-treatment of iron and steel. To practical men it may not in the past have seemed of much concern to determine accurately the points W and V, or the changes noticed when heating steel, such as recalescence or retardation-points. But when it is proved, as Mr. Howe has so clearly done, that a comparatively small difference in the range of temperature may so considerably affect the ductility of the material under treatment, then it behooves those interested to pay the attention such observations warrant. To give one example alone, without doubt a more careful study of this branch of research would ensure stronger and safer railroad tires, axles, and other similar articles. As we increase the speeds and loads of our machinery, whether on land or sea, more consideration will have to be devoted to this important matter —the accurate heat-treatment of iron and steel.

W. J. KEEP, Detroit, Mich.: M. Pourcel, in his paper on segregation in steel, disposes of segregation in cast-iron in a very few words. Mr. Howe, in his *Metallurgy of Steel*, treats the subject more fully. In making test-bars of varying composition, I have often discovered evidences of segregation in sulphur as well as carbon, but not having analyses of the specimens I have not recorded them. I have also found in castings that did not run full, as indicated in Figs. 1 and 2, that the pressure of the inflowing metal would sometimes force iron through the thin shell in the form of small spherical drops.

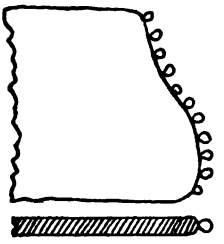


FIG. 1.

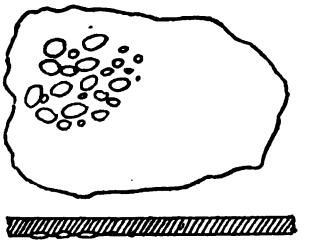


FIG. 2.

A case in which this has given much trouble was where the castings were of considerable size and about one-eighth of an inch thick, and where two currents of iron met. At such a place the inflowing metal would be forced through the lower surface of the casting into the sand of the mould. This liquation stands out on the surface like drops of sweat. It is very difficult to separate the white iron of these sweat-beads from the gray iron about them. An analysis of the beads (accompanied by a considerable amount of adhering gray iron) gave C, 2.64; Si, 2.47; P, 1.00; S, 0.042; Mn, 0.91. The gray iron alone contained C, 3.01; Si, 2.48; P, 0.95; S, 0.035; Mn, 0.90. The following cases (Figs. 3, 4, 5 and 6) of stratification could be seen at the Exposition in the iron-exhibit in the Swedish Building. Swedish pigs are cast in an iron pig-bed, and quite often in the form of slabs from 8 to 10 inches wide, and about a foot and a half long. These figures are drawn to a scale of four-tenths of an inch to one inch, and represent a fracture across the center of a slab. The brand-mark is shown alongside the cut.

Fig. 3 shows an iron capable of taking a chill, as shown by the white stratum at the bottom. The cooling was so rapid that hardly any of the carbon could take the graphitic form. At the top of the

slab, where cooling was less rapid, graphite formed, giving a stratum of gray iron.

Fig. 3.

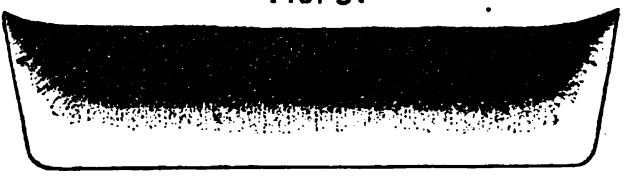
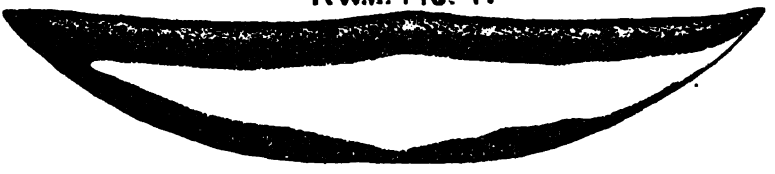


Fig. 4 represents a slab which I am told positively was cast in an iron-bed. In spite of the cooling influence of the mould, the lower shell for one-eighth of an inch is gray, the temperature being that required for the formation of graphite. The upper surface exposed to the air is very light-colored, and is full of white spots. Beneath

RW.n. Fig. 4.



this portion is half an inch of dark graphitic iron. The center of the slab is perfectly white for three-quarters of an inch in thickness, surrounded, as I have described, by perfectly gray iron, showing that, at a certain temperature, silicon and carbon will combine with the iron and produce a white casting independently of any outside chilling influence. In this exhibit are perfectly gray slabs of this brand, and also slabs perfectly white, all cast in the same kind of moulds.

I was told that this stratification is of very common occurrence in Swedish iron, and that it is caused by the silicon content being just between that necessary for the production of gray and of white pig. Being neither the one or the other, the stratified iron is considered rather undesirable.

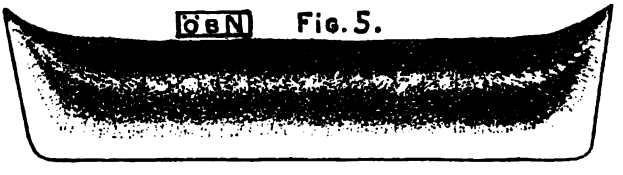


Fig. 5 represents another slab cast in an iron mould, and has a

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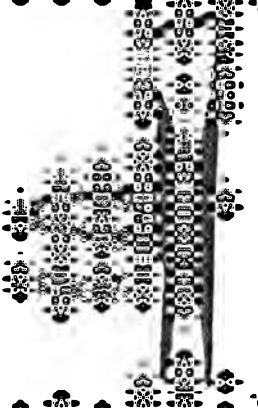

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portion was, there-
con.
; graphitic C, 1.874;
ite: total C, 3.861;
2,742; Mn, 0.501.
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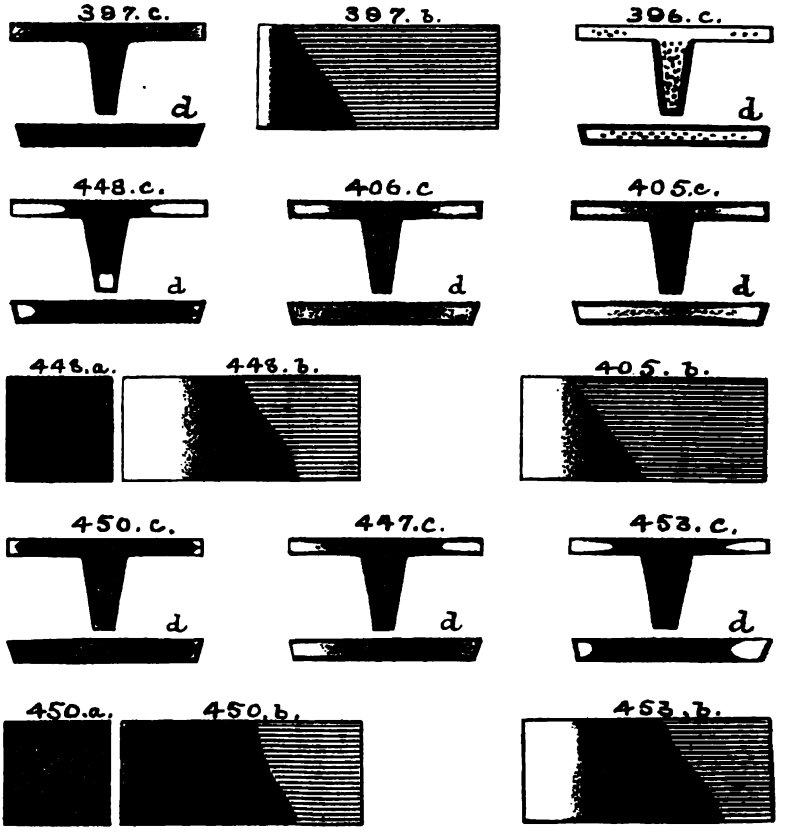
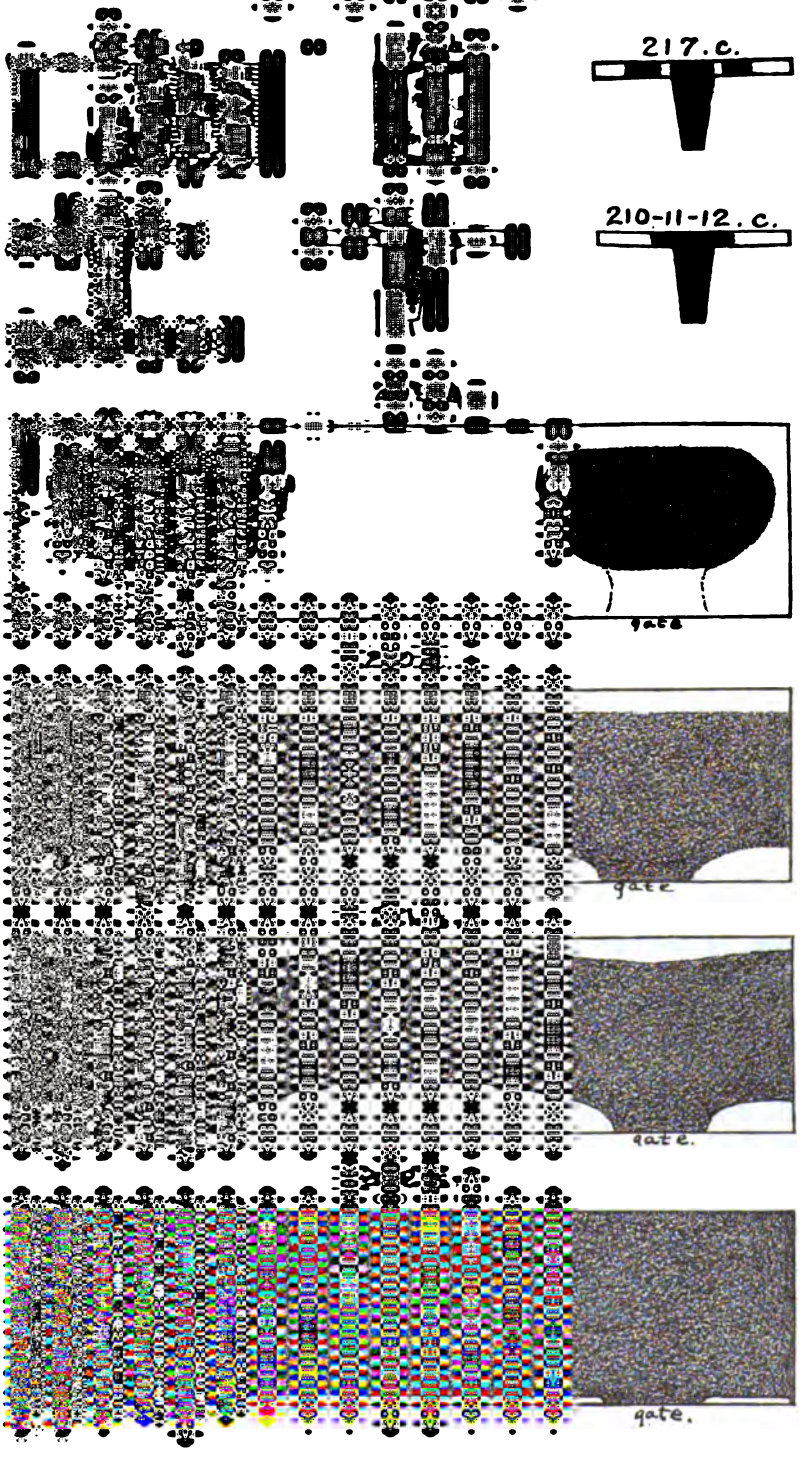
of sections of castings, all of the true size, showing stratification or segregation in various forms. Figures marked *a* show the fracture at the center of a test-bar one foot long and one-half inch square. Those marked *b* show the end of the same bar, with the side broken away, showing the depth and character of the chill.

Those marked *c* are cross-fractures at the center of a bar with



the section shown and one foot long. The bar is run from one end, and the stratification extends nearly or entirely the length of the bar. Those marked *d* are cross-fractures of a bar 1 inch by ½ inch and 12 inches long, run from two gates on one side. The stratification is influenced by the gates.

No. 208 *d* shows a fracture through the gate, and it would be the same for 209 *e*, and it would be the fracture if made between the gates of 210 *e* and 211 *e*. The drawings 210, 211 and 212 show the structure of these thin test-bars viewed from the flat surface.


217.c.
210-11-12.c.
gate.
gate.
gate.

Nos. 397 *b*, *c* and *d* show the fracture of a bar that has none of this tendency to segregate. In all fractures the amount of graphite is shown by the darkness of the fracture.

T. BERGENDAL, Sweden: With reference to the statement of Mr. Keep concerning some Swedish pig-iron, I only beg to remark that the mixed gray and white metal for the "Lancashire" refinery process frequently changes in texture according to the more or less basic character of the charge on the blast-furnace, all other circumstances remaining the same. Thus, for instance, when the slag is more basic, a pig-iron will be obtained in which the gray and white are sharply divided, while, with a more acid slag, the colors will be more irregularly mixed. Which of the several kinds is to be preferred depends on the purpose for which the pig-iron is to be used, the manner of its treatment and the desired quality and nature of the final product.

In regard to the fracture shown in Mr. Keep's Fig. 4, the texture may have been produced by an (evidently present) amount of manganese, and by the circumstance that the mould had not been sufficiently cleaned before casting the iron.

PROF. E. D. CAMPBELL, Ann Arbor, Mich.: As Mr. Keep has said, the subject of segregation in cast-iron has been disposed of by M. Pourcel in a few words. It is generally held that we shall find the greatest amount of metalloids in that part of a casting that has remained fluid the longest. This is, I think, true in most cases; but there are exceptions to this rule, which I had occasion to notice some time ago when making analyses of car-wheels. One would expect, if an analysis were made of the metal in the hub of a wheel, that, as the hub remains fluid longer than any other part, that metal would contain more metalloids than any other part of the same wheel; but this is not the case, as will be seen from the analyses given below. The drillings from the rims of the wheels cited were obtained by drilling from the inner side of the rim outward until the drill was stopped by the chill on the wheel. This gave a sample of the inner portion of the rim not including the chill. The drillings from the hubs were obtained by drilling into the face of the hub, parallel with the axle and nearly to the center of the hub. From an inspection of the analyses it will be noted that silicon, phosphorus and manganese are all higher in the rim than in the hub, thus showing a local segregation brought about by the chilling of the tread of the wheel. This chilling seems to have the effect of compelling the metalloids to take a place in the adjacent metal, thus

making the inner portion of rim richer in silicon, phosphorus and manganese than even the hub, which must be itself richer than the mother-metal from which the wheel was cast.

Analysis of Four Wheels.

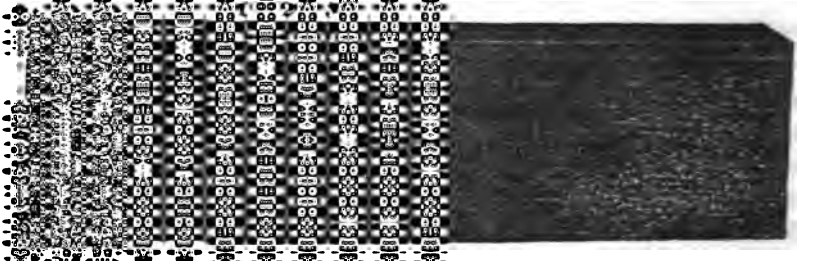
Wheel.	Silicon.		Phosphorus.		Manganese.	
	Rim.	Hub.	Rim.	Hub.	Rim.	Hub.
A.	.715	.580	.284	.265	.228	.213
B.	.672	.616	.301	.287	.238	.207
C.	.654	.516	.367	.360	.236	.212
D.	.482	.452	.266	.250	.324	.317

The phenomena of diffusion, although not identical with those of segregation, are so closely related that a few facts in regard to diffusion may not be amiss in a discussion of segregation. The statement has been made by a well-known metallurgist that as carbon will diffuse from a hard to a soft steel if the surfaces are perfectly free from oxide and the metals are brought to a bright red heat, it follows, because of this diffusion, that the carbon must be in an uncombined condition. He assumes this as one proof that carbon in steel is only mechanically mixed with the iron and not in a state of true combination, even in hardened steel. If we can bring experimental evidence to show that we can get diffusion of an unquestioned chemical compound, *e.g.*, sulphide of iron, then the statement that the phenomenon of diffusion is proof that the diffusing element must be in an uncombined condition is without weight; it may or it may not be chemically combined. We hope to complete at the University of Michigan a number of experiments on the diffusion of sulphides and phosphides through iron and steel, and we shall take up other compounds, if time permits, so as to try and see if a little more light cannot be thrown on the question of diffusion. The set of experiments reported below was carried out under my personal supervision by my assistant, Mr. W. G. Wallace.

The metal operated on in the first set of experiments was an inch by two-inch bar of structural steel (see Fig. 1) containing: carbon, 0.170; silicon, 0.000; phosphorus, 0.110; manganese, 0.410; total sulphur, 0.0737. This bar was cut up into pieces about 8 inches in length for the tests.

Experiment 1.—One piece of the above bar was taken, and a $\frac{3}{16}$-

in the edge of the bar and ole was then nearly filled with iron, and was closed tightly by lphide of iron used contained ng and plugging the hole, the and the muffle was gradually l working-heat for an assay- ur and a quarter. After at- ept at this heat for ten hours ly, and the bar was removed. raping this off and measuring eighth of an inch in thickness in a planer and dressed until t metal showed. A transverse original hole and the cuttings into the original hole it was for a thin, black film. Four



ing Absorption.

rallel with the original hole; riginal hole, and the others be- inations of the sulphur in the illings showed no increase over of the determinations will be descriptions.

ch hole was substituted for the f sulphide was introduced; the r was heated as in the first case, four instead of ten hours. On the plug was found to be com- and on cross-cutting over the disappeared completely. The e hole was not in the least al-

tered in structure, as will be seen from Fig. 1 taken from a photograph of the bar after dressing and drilling for analysis. Analyses of the cuttings over the hole and of drillings from holes tangential to the original hole again showed no appreciable increase in sulphur, although the amount added was approximately 0.1 per cent. in weight of the bar operated upon.

Experiment 3.—Having seen from the above that the sulphide would diffuse completely through the bar, we tried to see if we could find approximately the rate at which it was absorbed. Another piece of steel was taken with a $\frac{1}{2}$-inch hole, as in Experiment 2, and 8.6 grammes of sulphide were introduced. Instead of plugging the hole, it was covered with a small piece of iron that was lifted only to inspect the bar. The furnace was brought to a bright heat before the bar was introduced. The bar was put in at 10 A.M., and withdrawn at 10.45, as soon as it had attained a full heat. The sulphide was fused, but little or no absorption had taken place. The bar was returned, and withdrawn again at 11.15, when all sulphide had been absorbed. An additional 2.5 grammes of sulphide was put in, by which time the bar was cooled to a moderate red, and it was returned to the furnace, and withdrawn at 11.35. The sulphide had just fused. Returned and withdrawn at 11.47, it showed the sulphide about one-third absorbed; returned and finally withdrawn at 12.00, when all the sulphide was again absorbed. This made 11.1 grammes in all that had disappeared. An analysis of drillings from a hole parallel with the original, and $\frac{1}{8}$-inch from it, showed no increase in sulphur over the original. White fumes were noticed emanating from the bar on withdrawing it from the furnace, and the scale on the outside was noticed to contain rings of a whitish color in places, especially on the sides of the bar in the vicinity of the hole. A portion of the scale showing more or less of this whitish substance was analyzed, and showed 2.601 per cent. sulphur, thus indicating where a part at least of the sulphur had gone.

Experiments 4 and 5.—These two experiments were almost exactly the same, except that in No. 4 one half-inch hole with 8.5 grammes of sulphide was used and in No. 5 two half-inch holes containing 15 grammes were used. The bars were put in a Hoskins muffle-furnace in such a way that, with the holes uncovered, the progress of absorption could be watched. The bars began to absorb the sulphide in a little less than an hour. When about one-third or a little more of the sulphide had been absorbed, the bars were withdrawn and quenched in water. As in No. 3, white fumes were noticed; and on introducing the bars into water, a distinct odor of

hydrogen sulphide was detected. In neither of these cases was the amount of sulphur, in drillings taken within one-eighth inch of the original hole, any higher than in the original bar.

In the table given below, I have used the term "soluble sulphur" as indicating that portion of the sulphur which passed over as hydrogen sulphide on dissolving the steel in hydrochloric acid, and "insoluble sulphur" as indicating the sulphur remaining with the insoluble residue in the generating-flask. The solution in the flask in no case contained any sulphur.

Test for Absorption of Sulphur—Analyses of Drillings.

Experiment No.	Original Bar.			Cutting Over Hole.			Hole No. 1.			Hole No. 2.			Hole No. 3.			Hole No. 4.		
	Sol. S.	Insol.	Total.	Sol. S.	Insol.	Total.	Sol. S.	Insol.	Total.	Sol. S.	Insol.	Total.	Sol. S.	Insol.	Total.	Sol. S.	Insol.	Total.
1	.0663	.0074	.0737	.0671	.....	.....	.0646	.....	.....	.0680	.....	.....	.0642	.....	.....	.0691	.....	.....
2	.....	.....	.....	.0669	.0033	.0702	.0671	.0052	.0723	.0696	.0063	.0759	.0678	.0034	.0712	.....	.....	.....
3	.....	.....	.....	.....	.....	.....	.0677	.0054	.0731	.....	.....	.....	.....	.....	.....	.....	.....	.....
4	.....	.....	.....	.....	.....	.....	.0676	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	.....	.....	.....	.....	.....	.....	.0655	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[NOTE BY THE SECRETARY.—Just after the sheets containing the immediately preceding pages had been printed, I received from Prof. Campbell a letter informing me that later investigations, conducted under his direction, had led him to suspect that the results of experiments on the diffusion of sulphide of iron, as reported by him in this discussion, may not exactly express the true significance of the phenomena observed, since what seemed to be a clear case of diffusion may prove to have been a case of capillary action. This doubt will be resolved by further experiment. The conclusions concerning segregation in car-wheels, reported by Professor Campbell (pp. 620, 621), are not affected.

I take the liberty of adding (what many of the professional colleagues of Prof. Campbell already know) that this distinguished investigator has suffered, through an accident in his laboratory, the total loss of sight, a calamity which would have ended the scientific labors of a less skilful and ardent student. But, it is the mind that sees, and Prof. Campbell's work is still remarkable for brilliancy and accuracy, though the physical details are now executed by the hands and eyes of others. The doubt which he has frankly expressed in this instance is, indeed, an added proof of his characteristic acuteness, since it is simply a recognition of the personal equation and judgment of his assistant, as an undetermined factor which ought to be further tested. Concerning the determinations of segregations in car-wheels, Professor Campbell writes: "They are all right, as I did that work myself before my accident, and am satisfied with those results."—R. W. R.]

HENRY D. HIBBARD, Highbridge, N. J.: There is one of the ills that steel is heir to which I conceive to be the result of a kind of local segregation, namely, the well-known hard spots sometimes met with near the surface in machining both castings and forgings.

It is common to ascribe these to particles of spiegel or ferro-manganese remaining unmelted or unmixed in the steel. This explanation seems to me to be entirely inadequate. They occur in cases where it is impossible that any of the spiegel could remain unmelted or unmixed. As far as I have been able to observe, they occur in steels cast at too high a temperature.

My theory for the case is that there is local segregation of the impurities at many places, each of which forms a hard spot near the

outside of the mass of pasty steel, each hard spot being a joint where the impurities were collected. Gaseous impurities are collected as well; and I have often noticed in forgings which have been insufficiently worked under the hammer, that almost every hard spot had a partially closed-up hole close to or directly in it.

The cause which produces such local segregation in some ingots and not in all, I believe to be chiefly too high a casting-temperature. Cold steel sets too quickly around the surface for such action. With both hot and cold steel there will be a collection of impurities in the center at the upper end, which will be the more pronounced the larger the ingot and the higher the temperature at which the steel is cast.

A. C. CUNNINGHAM, Wayne, Pa.: The researches and investigations of such eminent authorities as A. Pourcel, H. M. Howe and others on the subject of segregation, leave but little to be done in this line except the accumulation of additional data, and the study of conditions and methods which will reduce it to a minimum.

From the results observed we infer that segregation, or the "separating out" of the impurities and constituents of steel, follows a natural law; that the constituents of the steel tend to accumulate along the axis and towards the top of an ingot, or the portions which solidify last; that the greatest segregation is found at the top of ingots, and that it is a maximum in large, or hot-cast ingots.

We note further that the dangerous elements of steel, phosphorus and sulphur, are amongst those that segregate most strongly, and that the greater the percentage of these elements present, the more strongly will they segregate.

Had these facts been brought out on the general introduction of steel for structural purposes, it would have been a severe blow to its ardent advocates, and a triumph for the conservatives who maintain that iron is the only fit metal for such uses. In spite of our lack of knowledge on this most important subject, steel has gradually made its way to the most important place in structural metals; and when segregation is provided for, and under some control, our confidence in steel need seldom be shaken.

Up to the present time the question of segregation has been a problem left for the manufacturer to deal with, but with the knowledge of its laws and effects which we now have, the time seems ripe for its consideration by engineers in the preparation of specifications for steel.

The introduction of chemical limitations in specifications is of

comparatively recent date, and is not, even now, general. The limitations imposed have generally, and rightly, been upon the two dangerous elements of the steel, phosphorus and sulphur, and more generally the former than the latter. In specifying chemical limits, the engineer has based his calculations upon the ladle-analysis from which the manufacturer grades his steel, and which fairly represents the average chemical qualities of the steel.

As a result of the investigations in segregation, the engineer may now safely assume that, while some of his material may be below the limit which he has specified for certain elements, a certain portion of it will surely be above, and no single piece of the material will be absolutely homogeneous.

As long as chemical limitations of steel are determined by the ladle-analysis alone, special attention to the temperature of casting, form of ingots and manner of cooling, cannot be expected, beyond the ordinary requirements for the protection of the manufacturer; nor can more cropping of ingots be looked for than will give approximately sound material.

It is a fortunate thing that, in the great majority of cases, the rivet-holes punched in structural material are in the lines where the segregation is the lightest. In some of the cases shown below, however, accumulation of highly segregated material might become a source of serious danger.

The tendency in structural designing is towards the use of longer and longer material in the nature of shapes, plates and bars, and a proportional increase of section. Manufacturers have endeavored to keep pace with this demand, until the limit of the capacity of heating-furnaces, rolls, and mill plants in general has been reached; in consequence of which, we may naturally expect, besides defects due to inadequate rolls and machinery, that some of this material must be highly segregated at the upper ends. Doubtless, many failures of eye-bar heads, which have been attributed to improper working, might have been traced to segregation in an insufficiently cropped ingot.

If segregation has such serious and marked effects upon the qualities of steel, why have we not had more numerous and extensive rejections of the metal for important structures? The answer is contained in M. Pourcel's paper, where the difference in behavior of tests from the top and bottom of a boiler-plate is described.

Very few, if any, specifications exercise any authority over the

manner in which tests are selected, and manufacturers have received the benefit of any doubts, by being allowed to select tests at their discretion. The effects of segregation, if not its laws, have long been known as to its bearing upon the results of tests; and a little study and experiment on the part of the manufacturer will soon show the most advantageous place and manner for cutting tests. An illustration of this is given in Fig. 2.

The possibility of still further concealing the true nature of the material may be seen in the fact that attached coupons on plates may be annealed or hardened by placing them between hot plates of iron, and then cooling them slowly or quickly.

A specification extensively used throughout the United States for some years past provides for the acceptance or rejection of steel by tests made on rods $\frac{3}{4}$ inch in diameter, rolled from small ingots, without regard to the section to which the remainder of the material is to be rolled. It is to the credit of our manufacturers that, under this specification, the great majority of them have provided tests from the finished sections.

The important question is, How shall engineers protect themselves against segregation in the material which they use in their structures? The imposing of absolutely fixed lines upon the manufacturer is unjust and impracticable, and is a check to improvements which may result from experiment and observation. The correct method seems to be in the use of reasonable specifications, readily complied with and strictly enforced.

The following extract from a specification, recently prepared by the writer, is thought to provide for segregation, and still leave room for the manufacturer to work to the best advantage. The specification was intended to secure a high grade of Bessemer steel.

"Samples taken from the steel when poured shall show an amount of phosphorus not exceeding 0 06 per cent. and an amount of sulphur not exceeding 0.05 per cent. Drillings taken from any part of the finished material shall show an amount of phosphorus not exceeding 0.07 per cent. and an amount of sulphur not exceeding 0.06 per cent."

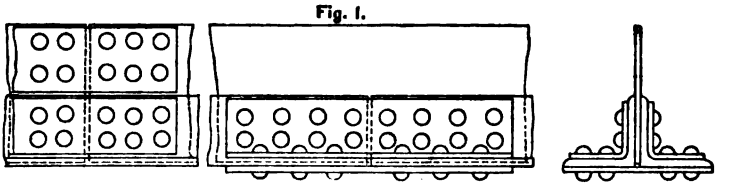
A steel which in the finished product should not contain more phosphorus and sulphur than specified for finished material, was wanted. The rather close limits between the ladle-test and drillings, which would naturally be taken from the most highly segregated parts, were so made in order that the manufacturer should have every

advantage which his ingenuity or experience could suggest for reducing the segregation to a minimum. This specification reduces the majority of manufacturers to extensive cropping of ingots, or the use of a much better stock than is represented by the ladle-analysis.

M. Pourcel suggests the use of new alloys as a remedy for segregation, and, doubtless, much can be accomplished in this direction, but the treacherous elements, phosphorus and sulphur, still remain. While we are searching for new alloys for steel, we must try and control the old one as far as possible.

The following figures exhibit examples of segregation, more or less marked, which have been investigated by the writer.

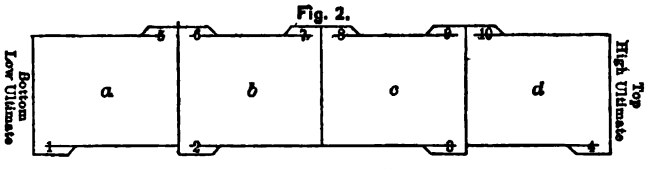
Fig. 1.



Splice-plates.

It is possible that the abutting material in the splices shown in Fig. 1 may be highly affected by segregation, as well as the splice-plates themselves.

Fig. 2.



Test-Samples from Boiler-Plate.

A specification for boiler-plate requires homogeneous material having a certain ultimate strength. Fig. 2 shows how misleading tests may be taken. An ingot is rolled into four plates, *a*, *b*, *c* and *d*; preliminary tests on shearings show that with coupon at 1, the ultimate will be too low; that with coupon at 4, ultimate will be too high; while coupons at 2 and 3 will give tensile strength as desired. An arrangement of coupons as at 5, 6, 9 and 10, will pass all four plates. Should coupons 2 and 3 be doubtful, coupons 7 and 8 will probably save plates *b* and *c*, whereas coupons 1, 2, 3 and 4 might reject all four plates.

Fig. 3.

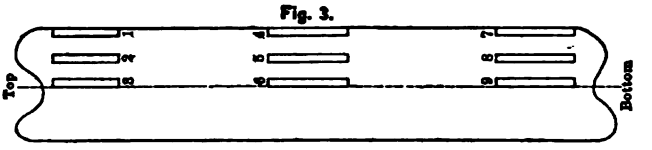


Fig. 3 represents the tests taken from a 16- by $\frac{5}{8}$-inch plate, rolled from a 10- by 18-inch ingot, and the analyses of drillings from broken test-pieces which are given in the table below, together with the physical results, show the effect of segregation upon tensile tests.

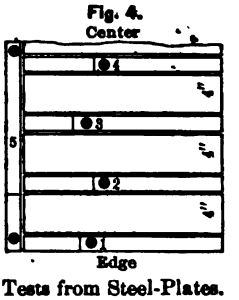
Analyses and Tests of Plate, Fig. 3.

(The ladle-analysis gave carbon, 0.15; phosphorus, 0.020.)

No.	Carbon.	Phos.	Elas. Limit per sq. in.	Ultimate per sq. in	Elong. in 8 in.	Reduced Area.
1	.15	.021	33,900	53,600	30.7	55.9
2	.14	.019	31,200	51,600	32.0	64.5
3	.17	.023	31,800	53,000	32.0	58.6
4	.15	.018	34,100	52,600	28.2	58.7
5	.17	.021	30,700	55,900	30.0	55.8
6	.16	.022	32,500	55,900	28.5	55.0
7	.16	.019	35,500	55,300	31.5	57.9
8	.16	.020	33,700	56,100	32.0	47.6
9	.16	.024	34,000	60,200	24.5	48.1

Another series of tests shows the segregation in a steel ingot, and

Fig. 4.



Tests from Steel-Plates.

its effects on tension-tests. An ingot was rolled into a $\frac{5}{8}$-inch plate, and cut into ten consecutive pieces, No. 1 being from the top. A test cut from the edge of each piece gave the following results:

Analyses and Tests of $\frac{3}{8}$-in. Plate.

(Ladle-analysis: carbon, 0.26; phosphorus, 0.050.)

No.	Per cent. Carbon.	Per cent. Phos.	Tensile Str'gth per sq. in.	Pr. ct. Elong. in 8 in.
1	.22	.064	75,900	9.50
2	.20	.058	69,700	20.00
3	.18	.034	64,200	25.00
4	.19	.043	65,700	25.00
5	.21	.036	65,000	27.00
6	.19	.038	63,700	25.50
7	.20	.039	66,600	23.80
8	.17	.030	61,400	26.00
9	.19	.040	66,600	24.00
10	.19	.040	64,600	23.80

Fig. 4 represents a 30- by $\frac{5}{16}$-inch steel plate, from which tests 1, 2, 3, 4, were cut, 4 inches apart, and test 5 was taken cross-wise. The drillings for analysis were taken, as indicated in the figure, the first four from near fractures, the fifth from the two ends of the test. The results show segregation and its effects in tensile tests.

Analyses and Tests from $\frac{5}{16}$-in. Plate.

No.	Carbon.	Phos.	Sul.	Elas. Limit per sq. in.	Ultimate per sq. in.	Elong. in 8 in.	Reduced Area.
1	.08	.077	.040	38,600	59,200	22.5	60.8
2	.08	.151	.063	39,900	66,600	24.5	59.1
3	.09	.141	.085	40,400	67,100	23.0	54.7
4	.09	.153	.085	40,100	66,500	20.0	52.0
5	See	below.	.....	37,700	66,500	15.0	27.3
5	.08 .09	.072 .152	.040 .080	Edge. Center.	.....	.....	.....

Fig. 5.

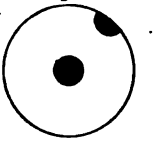


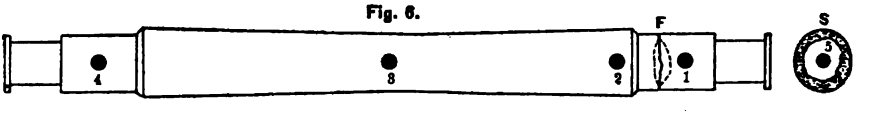
Fig. 5 represents the case of car-axles, which broke under drop-test. The drillings, taken as indicated, from center and surface of fracture, gave the following composition.

Analyses of Car-Axles.

Case No,	Drillings fr'm	Carbon.	Phos.	Mn.	Sul.
1	Surface.	.11	.106	.43	.055
1	Center.	.12	.111	.43	.055
2	Surface.	.16	.103	.43	.045
2	Center.	.15	.091	.45	.050
3	Surface.	.09	.080	.53	.050
3	Center.	.11	.090	.50	.049

Fig. 6 represents a car-axle which broke in the wheel-seat during service. Upon examination of the fracture of this axle, at F, it was found to contain a large cavity, surrounded by a skin of metal about ¾-inch thick, as indicated at S. Analyses of the drillings taken, as

Fig. 6.



indicated in the figure, from the surface of the axle and the center of the fracture, gave the following results :

Analyses from Car-Axle, Fig. 6.

No.	Carbon.	Phos.	Mang.	Sul.
1	.10	.062	.56	.052
2	.12	.045	.58	.043
3	.13	.046	.58	.044
4	.10	.050	.60	.054
5	.13	.086	.58	.093

A. A. STEVENSON and R. KENT, Burnham, Pa. (communication to the Secretary): Three or four years ago, owing to certain inexplica-

ble failures of tires, The Standard Steel Works authorized us to make a series of experiments to determine, if possible, the cause of the trouble. As a result of numerous analyses and physical tests, both from defective and experimental tires, we are able to present the following facts concerning piping and segregation, as they exist in the original ingot, and their effect upon the finished tire.

At the autumn meeting of the Iron and Steel Institute, in 1881, Mr. Snelus, in a paper on segregation, after giving analyses from various parts of different-sized ingots, makes the following statement: "It may be fairly assumed that ordinary ingots are not seriously affected by this redistribution," that is, by the segregation of the elements.

We think the following data show conclusively that this is not the case, and that there are conditions under which ordinary ingots are seriously affected by this redistribution of the elements.

Our opinion is that segregation and the existence of piping in the ingots used are the causes of by far the larger percentage of failures of steel tires. If this opinion can be substantiated, then, as the two evils of piping and segregation occur in the same part of the ingot, we are able, by the removal of that part and the utilizing only of the metal which is more nearly perfect both physically and chemically, to reduce the percentage of failures to a minimum.

Before going further we would define segregation as a concentration of a part of the elements in a certain portion of the ingot, forming compounds richer in these elements than the mother-metal. Concentration actually takes place in the part which solidifies last.

The elements in which there seems to be the greatest tendency to segregation are carbon, phosphorus and sulphur. We have in the course of our experiments found only one or two instances where there was a decided variation in silicon and manganese.

It must be borne in mind that the ingots in question are comparatively small; it may be due to this that segregation of silicon and manganese has not been observed.

Segregation occurs around the sides and at the base of the pipe; samples from the extreme top of an ingot usually give lower results than those from the body. We do not wish to convey the idea that the remainder of the ingot is perfectly homogeneous, since this is not the case. We do believe, however, that segregation to a damaging extent occurs in the immediate vicinity of the pipe only.

It is a question in our minds whether some of the hard spots found in tires after first or second turning may not be due to segregated

material. There is little doubt that the majority are due to sliding of wheels. Whether or not a hard spot was due to segregation could readily be determined in any individual case by analyses of material from the spot in question.

In our experimental work the etchings have proved almost invaluable. From the etched surface samples for analyses can be taken intelligently, as there is a decided difference in appearance between the segregated and the non-segregated metal; that is, when segregation occurs to a marked degree. The etched surface shows the location of segregation by a porous or granular appearance. This is much more apparent in the etching itself than on a print made from it.

We are in the habit of referring to the segregated metal as being porous and to the non-segregated metal as being solid; wherever these terms are used by us they will be understood to have the above meanings.

The chief difficulty experienced is in getting enough material for a complete analysis from porous spots. The results are lowered by the addition to drillings taken for analyses of solid material surrounding the spots. Another point to be taken into consideration is the liability in taking drillings to get into solid material underneath porous spots.

We make a practice of etching one-half of the broken test-pieces as close to the point of fracture as possible, and we have yet to find a case exhibiting a marked variation in physical tests from the same tire, the reason for which was not shown by the etchings of the broken test-pieces. By following this plan we think a reason might be found for some of the inexplicable results that are met with in the testing of material. While it is a point hard to determine it seems that the line between segregated and non-segregated metal is pretty sharply drawn.

That a decided segregation may take place in a small ingot is shown by the following experiment:

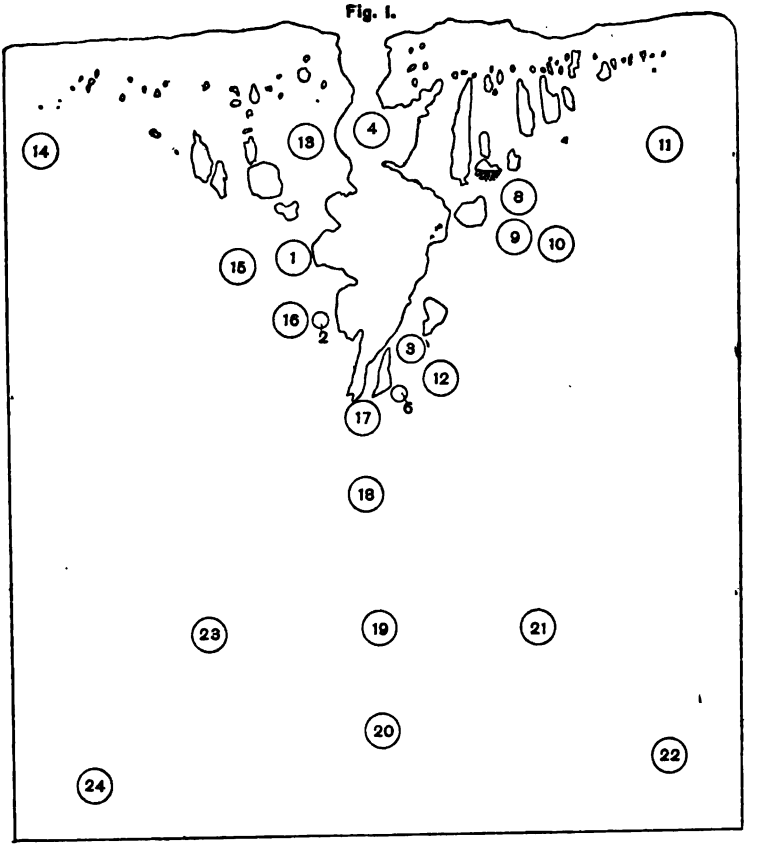
Fig. 1 is a sketch of a section of an ingot, cut lengthwise through the center. The ingot was 12 inches in diameter and 13 inches long, weighing about 400 pounds. It was one of a group, and was bottom-cast in a mould of cast-iron with a cast-iron cover. The sketch shows piping and also the location of holes from which samples were taken for analyses.

Fig. 2 is from a print of an etching and shows the portion of the ingot in immediate vicinity of the pipe. The segregated material can

be located by light spots on the print, the original appearance on the etching being granular. Fig. 2 is full-size.

In Table I. we give analyses from different parts of the ingot. They show, it seems to us, a very homogeneous metal outside the

Fig. 1.



immediate vicinity of the pipe. As will be seen, the sample from hole 13 gives the lowest results. Drillings from hole 2 were taken with a ¼-inch drill in order to keep as far as possible inside of porous spot. There was only enough material in the sample for a carbon-determination. Carbon was found to be 1 per cent., and from analogy there is every reason to believe the sample would have shown high phosphorus and sulphur.

In order to determine what results could be expected from a long ingot, the following experiment was made:

A bottom-cast octagonal ingot, 5½ feet long, 12 inches across the

flats at bottom and 11 inches at top, was cut lengthwise through the center. A good print was obtained from an etching of the section of this ingot, but, on account of its size, it cannot well be reproduced. There were only a few traces of segregation shown by the etching, and analyses showed that segregation had only taken place to a small degree.

We have not attempted to give all the analyses made of samples taken. A sufficient number, however, are given to show the character of metal in different portions of the ingot.

Table II. gives analyses of samples taken from the holes shown on Fig. 3.

We would call attention to several facts:

1. That samples from holes 16, 22 and 25 show higher results than are shown from corresponding holes on either side of the ingot;

2. That samples from holes 28 and 33 show about the same results as corresponding holes on the sides;

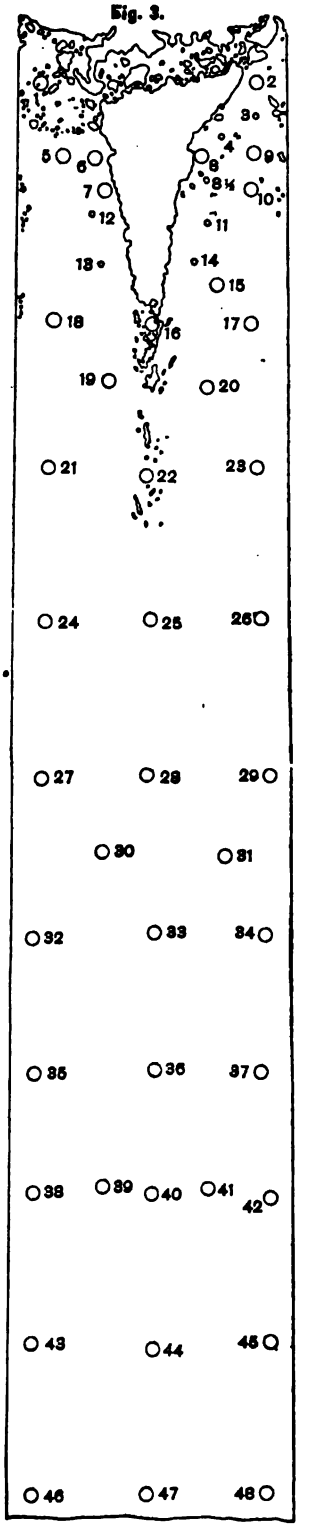
3. That samples from holes 36, 40, 44 and 47 show results slightly lower than samples from corresponding holes on the sides.

Silicon and manganese determinations made on samples taken from holes as shown in Fig. 3 gave the following results (Table III.).

The average analyses taken from the series of holes on the left side of the ingot, beginning at 18; from the middle of the ingot, beginning at 16; and from the right side of the ingot, beginning at 17, are remarkably close. We give these averages in Table IV.

The succeeding experiments show the

Fig. 3.



ished tires and also the results

from long ingots, the top or

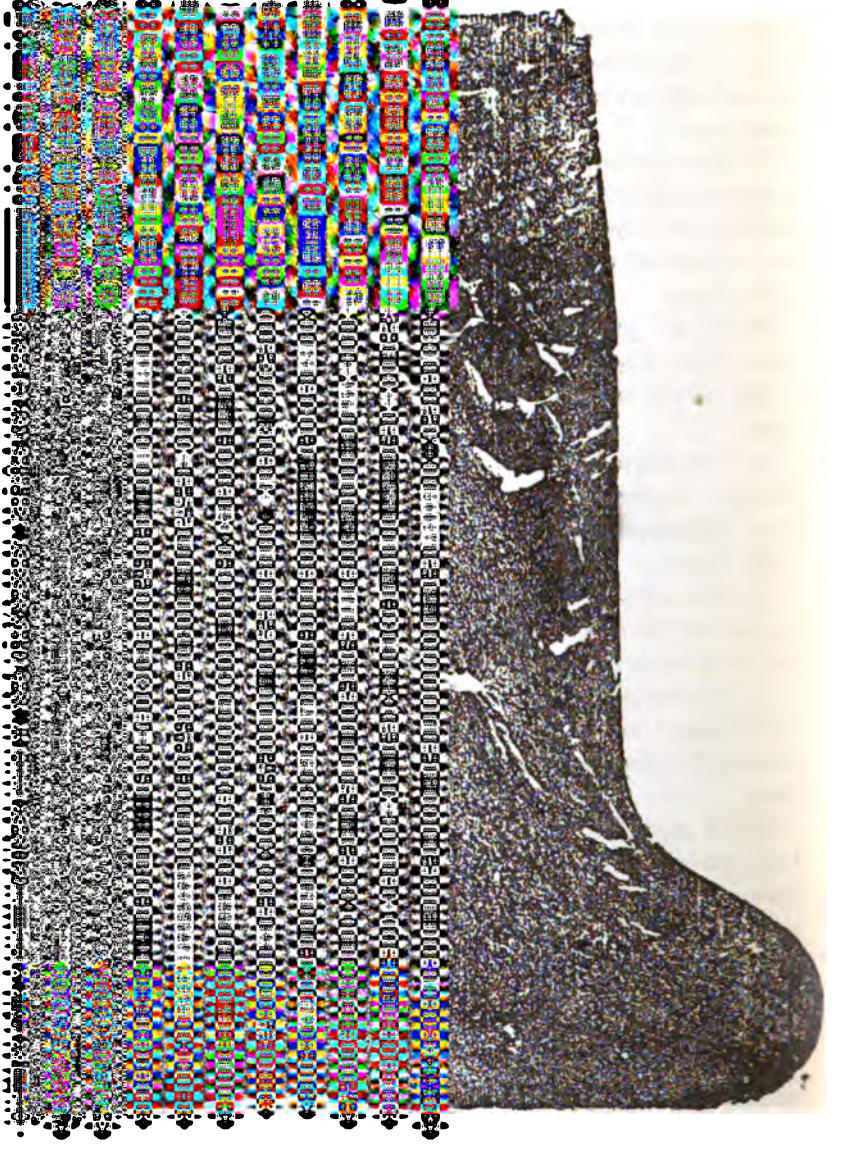


TABLE I.

Hole.	C.	P.	S.	Hole.	C.	P.	S.
1	.80	.073	.059	14	.58	.045	.028
2	1.00	.....	.....	15	.60	.046	.030
3	.75	.077	.064	16	.61	.053	.036
4	.54	.035	.....	17	.73	.071	.049
6	.77	.081	.....	18	.58	.045	.030
8	.61	.055	.044	19	.58	.043	.028
9	.65	.055	.046	20	.57	.043	.033
10	.59	.046	.032	21	.58	.045	.032
11	.59	.042	.033	22	.58	.047	.036
12	.59	.047	.033	23	.57	.045	.030
13	.53	.035	.024	24	.58	.047	.031

TABLE II.

Hole.	C.	P.	S.	Hole.	C.	P.	S.
1	.53	.050	.047	25	.57	.056	.061
2	.56	.048	.054	26	.57	.054	.054
3	.54	.....	.....	27	.58	.055	.058
4	.65	.....	.....	28	.59	.055	.053
5	.53	.053	.048	29	.56	.055	.057
6	.55	.057	.057	30	.54	.061	.053
7	.59	.059	.058	31	.56	.061	.054
8	.59	.061	.....	32	.56	.054	.054
8½	.70	.....	.....	33	.57	.052	.051
9	...	.048	.052	34	.58	.055	.056
10	.54	.052	.053	35	.59	.057	.058
11	.60	.....	.....	36	.56	.049	.052
12	.55	.....	.....	37	.58	.057	053
13	.60	.....	.....	38	.58	.053	.058
14	.62	.....	.....	39	.59	.057	.....
15	.55	.058	.047	40	.57	.050	.049
16	.65	.066	.063	41	.58	.061	.....
17	.56	.055	.052	42	.58	.054	.056
18	.55	.056	.054	43	.60	.058	.059
19	.61	.056	.....	44	.56	.054	.051
20	.60	.056	.....	45	.58	.058	.055
21	.56	.055	.054	46	.61	.057	.057
22	.58	.062	.060	47	.55	.049	.052
23	.57	.055	.059	48	.60	.058	.059
24	.59	.055	.053				

TABLE III.

Hole.	Si.	Mn.	Hole.	Si.	Mn.
18	.231	.745	37	.236	.763
23	.232	.....	43	.238	.763
27	.....	.763	44	.236	.....
28	.236	.763			

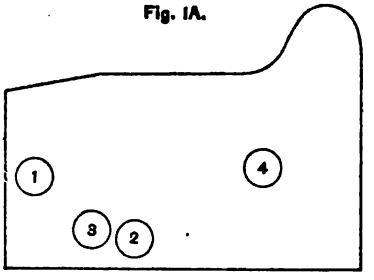
TABLE IV.

Left Side.	Middle.	Right Side.
Carbon..... .580	.573	.575
Phosphorus..... .0555	.0548	.0556
Sulphur..... .0561	.0548	.0556

Fig. 4 is a print from an etching of a tire made from a short ingot, say 12 inches long. The effect of piping in the ingot is at once apparent; in this case the flange-side of the tire corresponds to the bottom of the ingot.

The analyses given of samples, from different portions of the etched section, show a marked segregation, but not as decided as we sometimes find. The segregation occurs in the immediate vicinity of the pipe, as is shown by Fig. 1A, which gives the location of the

Fig. 1A.



drill-holes from which samples were taken for analyses. The most interesting feature in the case of this tire is the variation in physical results. Test-piece No. 2 was from the piped and segregated portion of the tire; No. 4, from the solid portion. Test-pieces were taken longitudinally, or, we might say, in the direction of the grain.

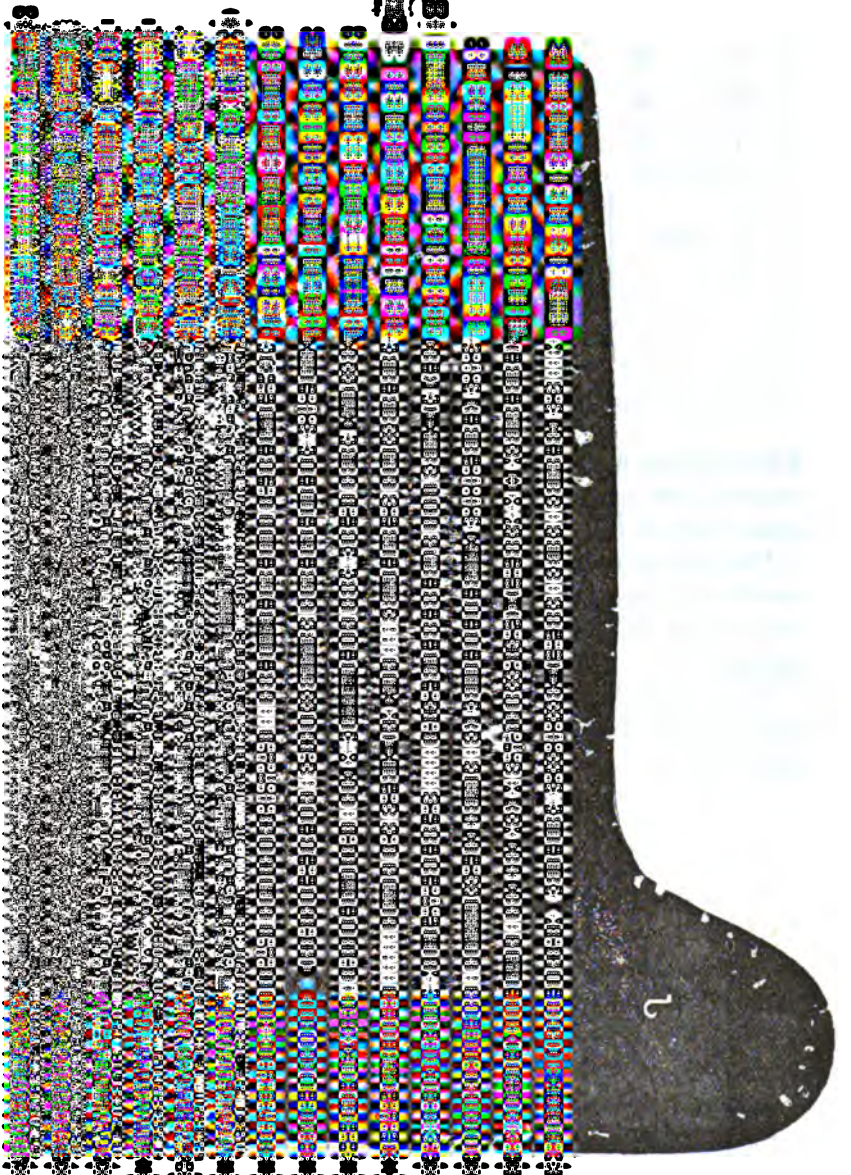
FIG. 5.

FIG. 6.

Fig. 5 is a print from an etching of broken test-piece, No. 2; Fig. 6 is a print from an etching of broken test-piece, No. 4. It is evident why test-piece No. 2 gave such poor results.

[illegible] ical results obtained

[illegible] showing one of the



[illegible] This tire broke after [illegible] was put in service.

TABLE V.

Hole.	Carbon.	Si.	P.	Mn.	S.
1	.59	.189	.052	.607	.043
2	.62	.200	.065	.626	.051
3	.65	.....	.062	.626	.050
4	.54	.185	.049	.580	.053

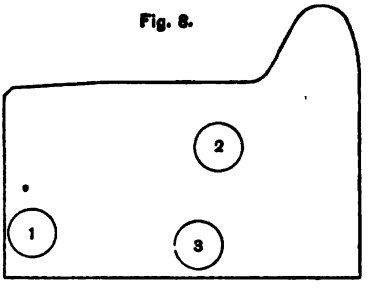
Mark.	Diameter of Test-piece. Inches.	Ultimate. Lbs. per Square Inch.	Elongation Per cent. in 2 inches.	Reduction Per cent.
2	0.564	87,200	2	2.2
4	0.564	104,800	16	3.07

The shrinkage was excessive, but, as other tires had stood the same amount, there is little doubt in our minds that segregation was, to a great extent, at least, the cause of failure.

The fracture was clean. With a small glass no traces of defects were found; the only peculiar feature being a polarized appearance; and etching showed the location of pole to be at point of worst segregation.

Fig. 8 shows location of holes from which samples were taken for analyses, and Table VI. gives results of chemical analyses and physical tests.

Fig. 8.



With regard to the carbon given for hole 3, we would say, that in order to satisfy ourselves and check our work, we had a determination made by Booth, Garrett & Blair, whose results are given, and correspond almost exactly with those obtained by us.

TABLE VI.

Hole.	C.	Si.	P.	Mn.	S.
1	.68	.....	.....	.....	.051
2	.72	.177	.063	.990	.....
3	.96	.196	.118	.905	.122

Mark.	Diameter of Test-piece. Inches.	Ultimate. Lbs. Per square in.	Elongation. Per cent. in 2 inches.	Reduction. Per cent.
2	.564	109,200	2	2.1
4	.564	130,000	10	13.0

Mr. H. M. Howe, in his *Metallurgy of Steel* says: "Heterogeneous composition usually implies heterogeneous strength and ductility; and the strength of a heterogeneous substance is usually nearer the strength of the weakest component or part than the average of all the parts. The piece tends to break down piecemeal. So with ductility." This being so, the character of such tires as are shown above is to be judged, not so much by the best results that can be obtained from a section of the tires, as by the poorest.

Fig. 9.

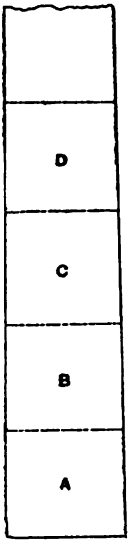
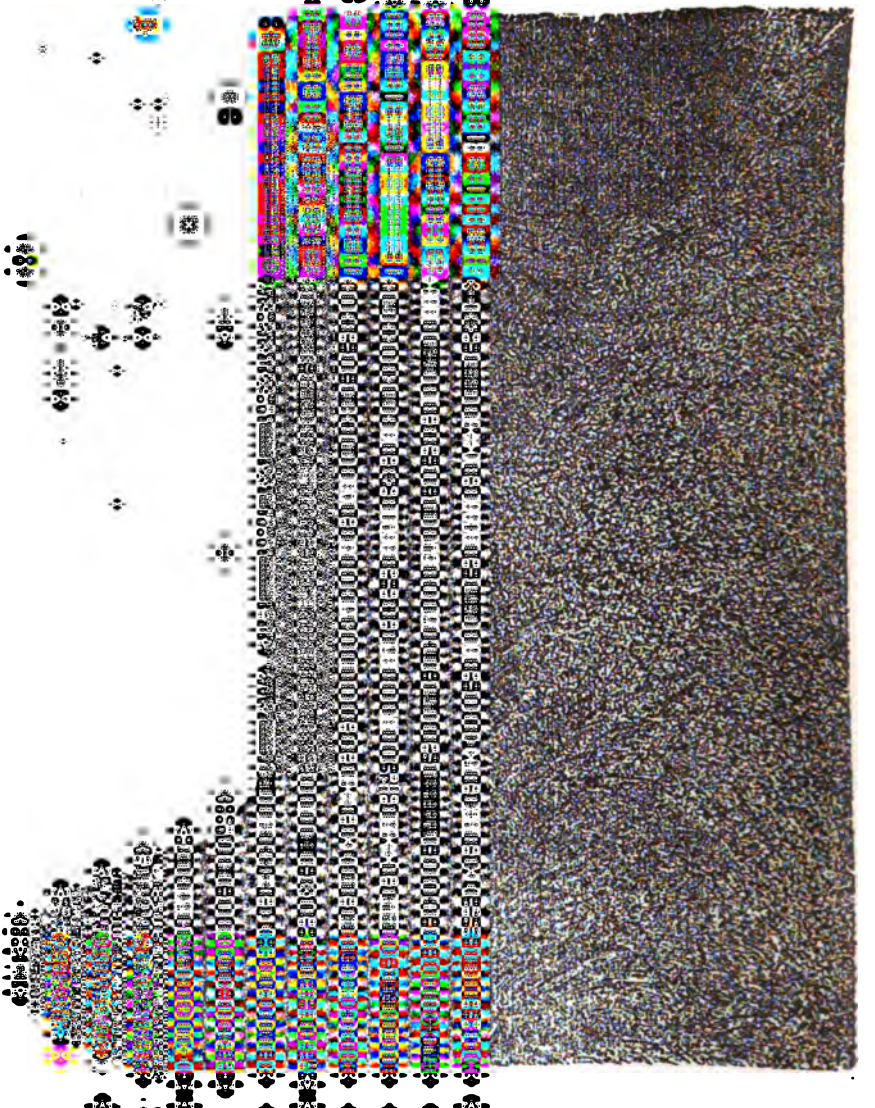


Fig. 9 is a sketch of an ingot 5½ feet long, from which four billets

ectively. These billets were
ingot, or the piece not marked,
anged in weight from 760 to



ng of a section of one of these
10A, 10B, 10C and 10D, show

Fig. 10A.

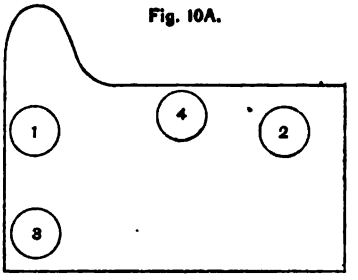


Fig. 10B.

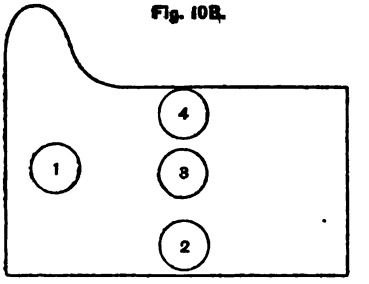


Fig. 10C.

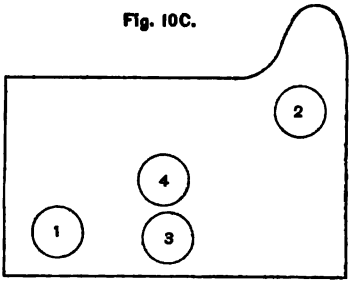
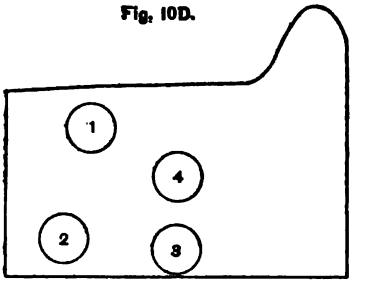


Fig. 10D.



the location of the holes from which samples were taken for analyses.

The tires were all cooled in air as they came from the mill, without being subjected to any further treatment.

Table VII. gives results from the four tires.

In every instance, test-piece No. 2 is from the face-side and No. 4 from the flange-side of the tire.

With regard to the chemical analyses we would say, that this steel was made some time ago. Our present specifications to the Otis Steel Company, Limited, from which we buy our steel, call for lower silicon and phosphorus, and in most classes of service, for lower carbon, giving (as shown by Table VIII.) lower ultimate tensile strength and increased elongation.

Fig. 11.

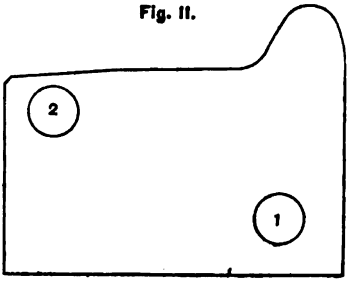


TABLE VII.

Tire.	Hole.	C.	Si.	P.	Mn.	S.
D.	1	.70	.390	.056	.761	.037
"	2	.69	.....	.062	.....	.036
"	3	.68	.....	.061	.....	.037
"	4	.68	.....	,061	.....	.036
C.	1	.66	.....	.056	.....	.033
"	2	.66	.....	.057	.....	.036
"	3	.65	.....	.060	.....	.037
"	4	.64	.....	.061	.....	.037
B.	1	.66	.412	.060	.752	.032
"	2	.66	.....	.058	.....	.033
"	3	.66	.....	.061	.....	.035
"	4	.66	.....	.062	.....	.033
A.	1	.66	.416	.054	.720	.035
"	2	.66	.....	.057	.....	.037
"	3	.68	.....	.056	.....	.038
"	4	.67	.....	.056	.....	.032

Tire.	Mark.	Diam. of Test-piece. Inches.	Ultimate. Lbs. Per sq. in.	Elongat'on. Per cent. in 2 inches.	Reduction. Per ct.
D.	2	.564	132,000	8	10.4
"	4	"	136,000	11	13.8
C.	2	"	135,000	9	9.4
"	4	"	135,000	10	13.1
B.	2	"	134,400	10	12.4
"	4	"	135,360	9	9.4
A.	2		134,000	9	10.4
"	4		133,600	11	13.1

TABLE VIII.

Hole.	C.	Si.	P.	Mn.	S.
1	.60	.215	.051	.633	.049
2	.60	.....	.052	.....	.050

Mark.	Diam. of Test-piece. Inches.	Ultimate. Lbs. Per sq. in.	Elongat'on. Per ct. in 2 in.	Reduction. Per ct.
2	.564	112,000	14.5	18.6
4	.564	108,400	14.5	18.0

Table VIII. gives the results obtained from a tire made from one of a number of billets, as in the preceding instance. The etching of a section of this tire showed no traces of segregation. The etchings of broken test-pieces showed no imperfections. The analyses correspond more closely with our present specifications.

Fig. 11 shows the location of the drill-holes from which samples were taken for analyses. As in previous cases, test-piece No. 2 is from the face-side of the tire and No. 4 is from the flange-side.

As a result of these and numerous other experiments the Standard Steel Works have abandoned the use of short ingots in the manufacture of tires, and are now using billets cut from ingots about 5½ feet long, of varying diameters, the top or piped end, which is also that portion of the ingot where segregation is liable to occur, being scrapped.

Before closing we would call the attention of those interested in this subject to an instructive series of etching prints in the Western Railway Club Proceedings of the meeting held in October, 1890. The prints are given by Mr. Rhodes in connection with a paper on steel-tired wheels and their fastenings.

The mixture used for etching is composed of three parts of sulphuric acid, one part of hydrochloric acid and nine parts of water.

P. H. DUDLEY, New York City: Mr. Osmond's paper on "Microscopic Metallography" places us under renewed obligations to him for his clear and concise statement of the present status of the new and important science which he has done so much to establish. While, as he says, "it has not acquired perhaps either the full consciousness of its future, or the full possession of its field," we must not forget that great advances have already been made in judging steels from the microscopical examination of their fractures and etched specimens showing their structure. At the present time, for steels requiring hardness and toughness combined, or high elastic limits in proportion to the ultimate strength, no one relies wholly upon the chemical composition except as determining the grade of steel. It is necessary to bring that special composition into the highest condition of which it is capable, by both mechanical and thermal treatment. In other words, we seek to render the geometric elements of structure or the mineral aggregates as small and homogeneous as possible.

The constructor of ordnance, observing his tensile bars in the testing-machines, judges the condition of the metal as much by the appearance of the surface under elongation as by the relations of the

elastic limits to the ultimate strength. If the bar elongates with a smooth surface, he knows that the mineral aggregates are small and elongating uniformly, and that the metal is in good condition. On the other hand if the bar in elongation presents a reticulated surface, the mineral aggregates are much larger, and elongation is taking place more rapidly through the planes of cleavage between, than through the aggregates. The metal is not in the best condition and must be improved by further thermal treatment.

The fact that chemical homogeneity by no means necessitates mechanical homogeneity should be extensively disseminated among consumers of steel rails, tires and ordinary grades of steel. Even at the present time there are many who suppose that a given chemical composition, irrespective of the form of the section and method of manufacture, means very definite physical properties in the rails and tires. This is largely due to the fact that steel rails, having been once molten, were said, when first introduced, to be homogeneous in contrast to the built-up pile of the iron rails. That crystalline forces, during solidification and subsequent cooling and heating of the metal, form the structure, was not considered. The care and time given to the manufacture of the early rails from small hammered ingots, and the many passes in the rail-trains at low temperature, gave to the small thin heads a solid structure of small mineral aggregates, presenting great resistance to flow from the pressure of the wheels of passing trains. From several of these old rails, etched specimens show, at 50 diameters, only a confused structure, the ferrite being distributed in small grains, and the pearlyte seeming to be granular. Each aggregate is so thoroughly interlocked with its neighbor that it is difficult to break it down and cause flow of any or all of its constituents. The wear of those rails has been so satisfactory as to raise hardly any question with regard to their homogeneity.

Generally speaking, the elastic limits of these rails ranged from 40,000 to 45,000 pounds, and the ultimate strength from 80,000 to 90,000 pounds, but, as I have said, each aggregate was thoroughly supported by those adjacent, and the wheel-pressures were carried and distributed so well that the breaking-down of the aggregates, due to the cold-rolling of the surface of the rails by the wheels, rarely exceeded 0.02 inch in depth. In many of the best-wearing rails it was less than 0.02 inch. The flow of metal to the side of the head was very limited and rarely occurred on the rails, except on curves and heavy grades. With the wheel-pressures of to-day a slight flow would be produced in such rails.

ture of such steel
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granular than the
parlance, "smooth
scope, the lamellæ

Fig. 2

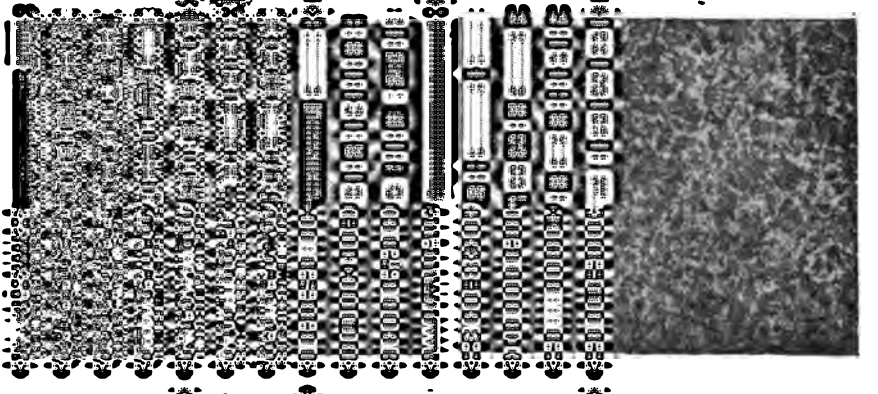
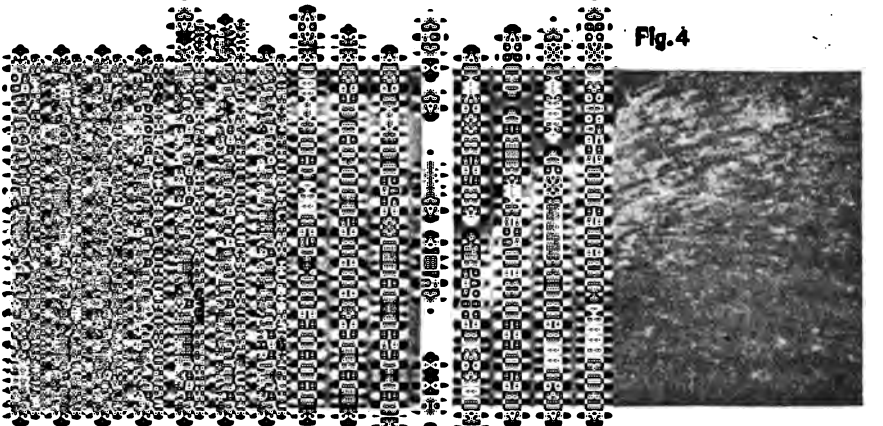


Fig. 4



and appear firmly

own in Fig. 2, the
are entangled with
ar markings. The
n of the granular
under high tem-

perature; the mineral aggregates are large and friable, and the surface of the rail breaks down more than $\frac{1}{32}$ of an inch in depth, readily flowing under the wheel-pressures. Under the microscope, the rails seem to be formed of scales or lamellæ, overlapping each other, of both pearlyte and ferrite. Little fragments are constantly becoming detached from the surface, or aggregates are flaking out, while larger masses are flowing to the side of the head and becoming detached in large fragments.

Such rails do not wear smooth. They have a dull luster, are pitted and present, in the track-man's parlance, a "mealy appearance." Figs. 2, 3 and 4 are micro-photographs, magnified 50 diameters, of the transverse structure in a deep-headed rail containing 0.26 carbon. Fig. 2 is from the head of the rail, just beneath the uninjured surface, and is very coarse in structure compared with Fig. 1. Fig. 3 is from the upper portion of the rail. The structure shows the aggregates broken down and under flow, even below the portion shown at the bottom of the picture. As the figure indicates, the top of the rail soon becomes a series of thin lamellæ, portions detaching as soon as the limits of elongation of the metal are reached. The surface-lamellæ of the rails are between the upper and nether millstone, and portions are ground to powder upon the passage of each wheel.

This is a practical illustration of axial compression in Mr. Osmond's cylinder, *A B* (Fig. 1, *Trans.* xxii., 244). In this case we have a series of superimposed lamellæ and flow caused by axial compression between all of their surfaces of contact, instead of the two similar halves of the cylinder placed upon their common base, *xy*, which he considers "an extreme case." Applied to rails, it is not an extreme case for the upper aggregates to flow, or portions of the metal to break out and flow over an interior gas-bubble or small pipe.

The flow on soft rails is not confined to a few lamellæ on the surface, but includes the breaking of several aggregates in depth, which finally flow until they overhang the edge of the rail, as shown in Fig. 4, then accumulate in larger masses, and eventually become detached. The wear and deformation of the rail-section largely depends upon whether the metal has great resistance to surface-flow or flows readily under the wheel-pressures.

Many years of experience with steel rails have clearly demonstrated that those which flow the least under the wheel-pressure give the most service, and those that flow the most wear and abrade with the greatest rapidity. This same remark applies to the flange-abra-

sion on curves. As I have already observed, the most serviceable rails have a fine structure, and small mineral aggregates, while the less serviceable rails have a coarse structure and large mineral aggregates, though, in many cases, the so-called chemical composition is identical. In the language of the constructor of ordnance, the condition of the metal for the grade of its composition was better for the service in the older than in the later rails.

It is now more than ten years since I made a broad thin head for rails of heavy sections. The roll-pressures and rapid cooling contribute to make the structure finer and more homogeneous in heads of this form than it was possible to secure in the deep-headed type then in general use.

During the past nine years one railroad has put 80,000 tons of my section into trunk-line service, and, notwithstanding over 50 per cent. increase in the wheel-pressures, the rate of wear of these rails has been very small. Many railroads, seeing its good wearing qualities, have copied the design, and it is now a leading type.

In 1890 I introduced a series of rail-sections of different weights, especially designed to produce a fine structure in the heads by the modern process of rolling. I designed also a special 95-pound rail for the Boston and Albany Railroad Company.

It was long ago observed that as the weight of the section increases, the difficulties of producing a fine structure in the head are also increased. In order to secure a fine structure in my large sections, especially in the Boston and Albany 95-pound, I proposed the following composition: carbon, 0.60; manganese, 0.80 to 0.90; silicon, 0.10 to 0.15; phosphorus, not to exceed 0.06; sulphur, not to exceed 0.07.

While great doubt was expressed as to the possibility of securing toughness with so high a percentage of carbon, we were able to control the condition of the metal in the final product of the rails, so that they were of unexpected toughness. The butts stood a drop-test of 2000 pounds, falling 20 feet, and rarely broke; while hundreds stood 2 to 4 blows of 30 feet before failing (supports 4 feet apart). At the side, the flange gave 16 to 18 per cent. elongation per inch under the point of impact of the drop. It must be said to the credit of President Bliss of the Boston and Albany Railroad Company, that he was willing to meet the manufacturers in a fair spirit and pay an increased price per ton for the high-carbon rails.

Up to the present date more than 150,000 tons of these high-carbon rails, in my series of sections of 60, 65, 70, 75, 80, 95 and 100

pounds, have been rolled; about nine-tenths of the product being in the weights above 70 pounds. The carbon is slightly decreased in the lighter sections and increased in the 100-pound section. The rails are showing good results in trunk-line service. Out of 75,000 tons, none of them failed in the exceptional cold of 1892–93 the temperature in many places being 30° F. below zero.

The structure in all the sections is now under study and comparison. The same section having been produced in many cases at different mills under different methods of manufacture, a vast field is offered for research.

Practically *for rails* the structure of the ingot cannot be omitted from consideration, as its solidity and continuity are quite as important as a good micro-structure. In brief I may say that my studies have enabled me to improve the texture and increase the toughness of the metal at the same time.

As to microscopic examinations, Mr. Osmond observes, that "natural illumination will serve only for very low powers, which are usually insufficient for this work." Dr. Sorby makes the same remark, which was strictly true when he made his research. Our American opticians were the first to produce wide-angled, low-power objectives, which, admitting so many rays of light, are well adapted for the study of opaque objects by natural illumination. I have found a 2-inch of 9 or 10 degrees aperture and a 1-inch of 30 degrees aperture to work well by natural illumination on either fracture or etchings. They cover a large field and stand deep eye-piecing for amplification. A ½-inch objective of 100 degrees aperture is also serviceable. Higher powers must be used for resolving the fine laminæ. For photo-micrography the wide-angled objectives are not essential, because the plate will be sensitive to lines in the spectrum far beyond what the eye can see.

A good photo-micrograph often shows what it is impossible to see under the microscope. An important point is, that a skilled operator can bring out structure on his plate, that the inexperienced eye could hardly recognize under the microscope. Mr. Osmond's photo-micrographs, taken with his simple inexpensive apparatus, are so excellent that they reflect his skill as an operator and his selection of plates, the emulsion of which was suited to the optical combination of his microscope and lamp. These are important matters.

The paper of Professor Martens, which I have not had opportunity to examine fully, is evidently another contribution of the highest value in this important department of research. And our fellow-member,

Mr. Sauveur, has confirmed and added to these results from abroad by his excellent work in the same line.

The importance of the subject of segregation, treated in M. Pourcel's paper, is coming to be generally recognized. The segregation of carbon, sulphur and phosphorus from the setting metal to that which solidifies last, often becomes a serious matter in rail-ingots. Upon examination of a number of rails broken during the severe cold of last winter, it was found that they were the top-rails from the ingots, with so great an excess of carbon and phosphorus as to be brittle.

ALBERT SAUVEUR, South Chicago, Ill.: For the last two years we have done considerable microscopical work at the South Works of the Illinois Steel Company, with gratifying results. Some of those results are embodied in my paper on the "Micro-Structure of Steel," presented at this meeting. I should only like to add here a few remarks which have been suggested to me by Mr. Osmond's paper, and which may be of interest at this meeting.

In regard to what Mr. Osmond writes concerning the polishing of the specimens, I would say that after numerous and repeated trials of all the polishing-agents used, and recommended for such work, we have adopted the following manipulations as giving the best and quickest results. The specimen is first cut to a convenient size ($\frac{1}{2}$ inch to 1 inch square and about $\frac{1}{3}$ inch thick will answer very well) and then gradually ground with the following polishers, in the order named:

1. Emery-paper, grade No. 2, mounted on a smooth board of wood.
2. Emery-paper, grade No. 1, similarly mounted.
3. Emery-paper, grade No. 00, similarly mounted.
4. Flour-emery, spread wet over a cotton cloth, stretched over a block of wood, with a perfectly plain surface.
5. Tripoli, wet, on cloth in like manner.
6. Best grade of jewellers' rouge, used wet on a piece of chamois-skin, stretched tightly over a block of marble.

In dealing with cast-iron, the first emery-paper may often be omitted. By following this process it will be found after a little practice, that a piece of steel can be polished and freed from even microscopical scratches in about an hour, while one-half hour is generally sufficient for samples of cast-iron. According to Mr. Osmond, oblique illumination is necessary to bring out certain *moiré* effects, which he describes. These effects we have not studied; but, unless used for that purpose, oblique illumination, which in all events may

only be employed with low powers, is not to be recommended; for it does not give a truly accurate appearance of the real structure of the specimen. As a source of light we use the oxy-hydrogen flame playing on a cylinder of calcium or of zirconium. The latter we have found to give as good results as calcium, but no better.

With such brilliant illumination the time of exposure for photographing is greatly shortened. Using orthochromatic plates (sensitometer 16 to 20) an exposure of from 4 to 10 seconds will be found sufficient for a magnification of from 50 to 100 diameters. With higher powers a longer exposure is necessary. A magnification of 500 diameters requires an exposure of from 30 to 40 seconds. We may say in passing that we have succeeded in obtaining some fair photographs of spiegeleisen magnified 1000 diameters. For that purpose we used a $\frac{1}{12}$-inch homogeneous objective and an amplifier.

We have assumed that cementite and the hard constituent of pearlyte are the same carbide of iron (probably Fe_3C), but we agree with Mr. Osmond that much more evidence is needed to settle this point. Until, then, however, we shall accept that hypothesis, first, because it accounts remarkably well for the structure of the different grades of steel; secondly, because there is as much, if not more, evidence in its favor than in favor of the opposite view; and, thirdly, because it is a simple one, which supposes the formation of only one carbide of iron in all steels not quenched.

I should like to call attention to the concordance between most of Mr. Osmond's conclusions and our own. Mr. Osmond says that the temperature, increasing the pearlyte, tends to form more and more large and regular polyhedra. I express the same view in my proposition IV.: "The higher the initial temperature the larger the grain for a given chemical composition." Again, talking of steel of medium hardness, Mr. Osmond says that quick cooling prevents the structure from developing, thus causing a finer grain. In my proposition V. I say, "The slower the cooling the larger the grain for a given composition." In my last proposition, however, I advance the view that the size of the grain is independent of the amount of work the metal has received. Mr. Osmond agrees to this, but only when the metal is finished at a relatively high temperature. If the forging or rolling has been continued until a lower temperature is reached, then Mr. Osmond claims that work, as such, does influence the structure of the metal. Of course, our proposition applies only to hot working; and, perhaps, the working-temperature at which the structural change, observed by Mr. Osmond, takes place is so low that it actually belongs to cold-working.

I was especially gratified to read the strong plea which Mr. Osmond makes in favor of the use of the microscope as a means of "reconstructing the thermal treatment to which the steel has been subject," and consequently of detecting improper heat-treatment. This is, indeed, one of the main points which I desire to emphasize in my paper.

H. M. HOWE, Boston, Mass.: With regard to some suggestions and criticisms contained in Prof. Marten's brilliant paper, I will say a few words.

While we must all agree in assigning the very greatest importance to the study of the micro-structure of steel, yet I think that we should by no means neglect the study of the fracture. Through it very important light may be thrown on the problem with which we are now confronted. The fracture takes place along planes of weakness. Now, the study of these planes of weakness and of their distribution and size under different conditions and after different conditions of heat-treatment may, it seems to me, be of incalculable benefit to us.

The use of specific names for the microscopic components of iron and steel I think is, on the whole, desirable as a matter of convenience. It is inevitable that in order to convey our ideas to each other we should make use of some kind of name. Before I suggested the specific names "Cementite," "Ferrite," etc., writers inevitably, even if unconsciously, fell into using names which were equally specific, but simply more cumbrous. There was "The pearly constituent," "The intensely hard compound," etc. The specific names which I gave were really no more specific than those which preceded them, but simply shorter and more convenient.

We cannot converse or write about such substances without using some sort of name. That name may be brief like "quartz," or it may be a long phrase like "the intensely hard, transparent, vitreous substance which crystallizes in the hexagonal system;" but such a phrase is simply a long inconvenient name. In the early stages of our knowledge names must be given provisionally, because we cannot fully distinguish the different substances, and we may incorrectly group under a single name some unlike substances.

We must recollect that in the early history of mineralogy names were sometimes incorrectly given, and sometimes two classes of minerals were incorrectly grouped under one name; but the errors and confusion which were occasioned by such error in nomenclature were insignificant, and not to be weighed against the advantage as regards convenience which the use of brief names for minerals gave.

Now, the only question is whether we shall give brief names, recognizable and easily written, to the microscopic constituents of iron, or use long and cumbrous ones. The brief ones have the great advantage of clearness and convenience. They have, perhaps, a slight disadvantage in suggesting a more complete knowledge than we actually possess, and also in that, when we do later come to a more perfect knowledge and have to remodel our nomenclature to fit the new facts, it may be less easy to drop them than it would be to drop long ones which had become odious through their inconvenience. I agree with Prof. Martens that we should all insist that, for the present, the specific names must be regarded as provisional.

I think that, running through Mr. Sauveur's interesting paper, there is a tacit assumption that there is a constant and known relation between the coarseness of the grain of steel and its quality or physical properties, and that in general (other things being equal) the finer the grain the better the quality. This assumption is natural and quite proper. I do not intend to criticise it in the least. But I do want to point out that we have now reached a stage in the study of these questions which makes it desirable that we should seek direct and accurate testimony as to the relation between the size of the grain and the physical properties, and that we should no longer take this important matter for granted. If the physical properties of every piece of steel which is subjected to microscopic examination were also determined, I think that it would be a great help to us, and that we could interpret the results of our microscopic examination very much more confidently. We must not forget that it is knowledge of the physical properties after all that is our objective point, rather than knowledge of the micro-structure. We do not study micro-structure for itself, but as a key to the physical properties.

The specimens on the table before us show that, in certain cases at least, the size of the grain as revealed by fracture gives no indication of the physical properties of the metal. These two pieces of the runner of a manganese-steel casting were originally one continuous piece. The fracture of one, as you see, is reasonably fine. This is the piece before water-toughening, and, therefore, while relatively brittle. The fracture of the other is extremely coarse and columnar; this is of the water-toughened and very strong and ductile metal. In short, here in one and the same continuous piece, and but a short distance apart, a relatively fine fracture accompanies weakness and brittleness, while a coarse columnar fracture accompanies strength and ductility combined.

THE GROWTH OF AMERICAN MINING SCHOOLS AND THEIR RELATION TO THE MINING INDUSTRY.

Discussion of the paper of Prof. S. B. Christy. (See p. 444.)

PROF. G. W. MAYNARD, New York City (communication to the Secretary): Prof. Christy, in his admirable paper on "The Growth of American Mining Schools," has overlooked the work done by the Rensselær Polytechnic Institute in its department of mining and metallurgy. This oversight is naturally due to the fact that the department was, for lack of money, discontinued in 1871. It was organized by the writer in 1867, starting with ten students, who had already completed the first two years of the civil engineering course in the Institute. The course covered two years, specifically devoted to mining, metallurgy and assaying, which, in connection with the two years' drill in the civil engineering department made a four years' course. During the four years of the existence of the department, thirty-five students took the course, of whom twenty-five graduated; and of this number eight have been members of the Institute of Mining Engineers, and the majority of them have occupied high positions in the profession. The equipment of the department was, at that time, second only to that of the Columbia School of Mines.

As Prof. Christy has cited other institutions which are not distinctively mining schools, but in which the mining course was subordinate to other courses, it seems to me that the work in this line carried out by the oldest engineering school in the country may very properly be referred to.

In addition to the regular mining course, a special course in assaying was given; and many young men were here prepared for positions in the mines and metallurgical works of the west.

PROF. GEORGE F. SWAIN, Boston, Mass.: I have listened with great interest to Prof. Christy's valuable paper, but there is one conclusion at which he arrives that appears to me entirely unjustifiable, and to which I desire to take exception.

Prof. Christy finds that of the total wage-earners in the United States in 1880, 10.41 per cent. were employed in "trade and transport;" 20.24 per cent. in "manufactures and mechanics," and 1.82

per cent. in " mining and metallurgy," and he draws the conclusion that the demand or field for civil, mechanical and mining engineers, respectively, was as these three numbers or approximately as 6, 11 and 1.

This conclusion depends for its correctness upon two assumptions: First, That the field for civil, mechanical and mining engineers arises entirely from the population engaged in trade and transport, manufactures and mechanics, and mining and metallurgy, respectively; and Second, That the demand for these three classes of engineers bears in each case the same constant proportion to the number of wage-earners in the three classes mentioned. The last assumption is really the only one necessary for the conclusion; but unless the first is made, the second will have no basis upon which to rest. If it be not granted, for instance, that the field for civil engineers *arises from* the population engaged in trade and transport, there will not be the slightest proof or reason for supposing that the demand for civil engineers is *proportional to* that population.

Neither of these two assumptions appears to me to be even approximately correct.

In the first place, the field for civil engineers arises very largely outside of the population engaged in trade and transport, and that for mechanical engineers outside of that engaged in manufactures and mechanics. The demand for mining engineers is probably more nearly dependent upon those engaged in mining and metallurgy.

The branches of civil engineering may be enumerated as follows: Sewerage, water-works, water-power, irrigation, topography, streets and highways, railroads, bridges, structural work, rivers, harbors and canals, and miscellaneous branches. Of these branches, sewerage, water-works, water-power, irrigation and topography are entirely independent of the population engaged in trade and transport, but are dependent upon municipal, agricultural and manufacturing requirements.

The only branches distinctly dependent upon trade and transport are railroads, rivers, harbors and canals; for the construction of streets and highways, and of bridges and roofs, is fully as dependent upon manufacturing, municipal and other requirements as upon trade and transport. No statistics are at hand regarding the relative number of civil engineers employed in the different branches of the profession; but it seems to me probable that not more than one-half, and very likely not as great a proportion, can be classed as distinctly dependent upon trade and transport.

Again, the branches of mechanical engineering are: Mill-, locomotive- and marine-engineering, and naval architecture. Of these, only mill-engineering is dependent specifically upon manufactures and mechanics, while locomotive-construction and marine-engineering are as distinctively related to trade and transportation as is railroad-construction.

As regards the second assumption, all that can be said is that there seems to be no reason that it should be true. If there is a demand for one civil engineer for every 1000 persons engaged in trade and transport, there is no reason why there should be a demand for one mechanical engineer for every 1000 persons engaged in manufactures and mechanics; and similarly for mining.

For these reasons, as already stated, the author's conclusions on page 449 appear to me entirely unwarranted.

I am ready to admit that the method used by Prof. Christy for estimating the relative demand for the three classes of engineers is, perhaps, the best available. I have none to suggest in its place. But I submit that, under the circumstances, the best available is worse than none at all, because its results are likely to be entirely misleading. Is it not better for us to rest in ignorance rather than to obtain a fictitious result, which is apparently based on figures, and yet may be, and probably is, far out of the way?

PROF. H. S. MUNROE, New York City: I have listened with much interest to Prof. Christy's paper, which is a very valuable addition to our knowledge of the demand and supply of mining engineers, a subject of great importance to all interested in mining education. I think, however, that the author underestimates that demand, in spite of his liberal allowances in our favor. He does not, I think, make sufficient allowance for the employment afforded by small mines and undeveloped mineral properties, especially in the west. These outnumber the productive properties ten to one.

Many of our graduates find employment at these small mines, where their training in geology, metallurgy, and mechanical engineering makes them especially useful. At first their responsibilities are not great, so that their lack of knowledge of the "art of bossing," and their limited experience in the actual business of mining, are less important. Making due allowance for these small mines, I think that the number of positions annually secured, and which might be available for our graduates, is much more than Prof. Christy's estimate.

When we compare these possibilities with the work actually done

by the mining schools, most of which, according to Prof. Christy, average but one graduate a year, it is quite evident that mining men are not taking advantage of the opportunities offered them by our mining schools. During the last winter I have been engaged in an inquiry to find out the reason for this. I sent out over a hundred circulars to prominent mining men, graduates of the School of Mines, members of the Institute, and others.

The discussion aroused much interest. To such a circular we usually expect to receive replies from 40 per cent. of those addressed. In this case I obtained answers from nearly 70 per cent. The replies, moreover, were exceedingly full, and were accompanied, in most cases, by long letters.

I have carefully digested this mass of material, and have arrived at some very interesting conclusions, which I hope to present to the Institute. At present I will confine myself to this one question, which I addressed to my correspondents, and which all answered:

"How do you account for the small demand, especially from the mining regions, for the instruction offered by our mining schools? Is it due to the course of instruction, or to causes beyond our control?"

The answers can be grouped under a few heads:

1. The demand for mining engineers is not large. Prof. Christy's paper comes in this category.

2. The course is difficult; and this, and high entrance-examinations, prevent men in the mining regions from taking the course, as their educational advantages are not very great.

3. An education at one of our mining schools costs much time and money, which deters the same class.

4. It is possible to become a mine-manager without going through the mining schools. This robs the young men of the incentive to sacrifice time and money and make the necessary effort to enter the school.

5. Most of the students who come to the mining school come from other localities and from other walks of life. To such men, life in the mining regions, at a distance from friends and among less agreeable surroundings, is not attractive.

6. Other professions consequently draw off students who would otherwise take the mining course. This is particularly the case in schools like the University of California, Washington University, Massachusetts Institute of Technology, and the School of Mines of Columbia College, where there are many parallel courses.

7. Prejudice, on the part of those most interested, in favor of practical men for responsible positions.

8. Miscellaneous considerations of minor importance.

All these causes have their effect; some are more important than others. There can be no doubt that the demand for mining engineers is much less than for civil or mechanical engineers. I do not believe, however, that this is the chief reason for the small demand for the instruction given in our mining schools. The demand for mining engineers is very much in excess of the supply, as is shown by the fact that applications from employers have for some years past greatly exceeded the number of graduates available for the positions offered.

While it would be interesting to take up these different causes as stated and discuss each, I propose here to refer to but one, the 7th, namely, prejudice in favor of the practical man for positions of responsibility. This prejudice is not confined to the practical men, or to those who have not had the advantages of a technical education, but is shared by educated men, and even by graduates of our own scientific schools, ready and willing to help the recent graduate in every way in their power, who, nevertheless, find that their duty to their employers compels them to promote their miners to be mine-bosses, assistant superintendents, and superintendents, rather than to appoint their fellow-graduates to these positions.

One of my correspondents, speaking of Pennsylvania practice, says:

"It is the exception and not the rule for the superintendent to be taken from the engineer corps. This is due not so much to a lack of practical knowledge of mining on the part of the engineer, as to the uncertainty whether he possesses the necessary executive ability to handle successfully the 500 to 1500 men of all classes and nationalities that will be under his charge; and any weakness in that particular is apt to be more expensive to the company than any mistake which a mine foreman of tried executive ability would make from lack of a technical education."

The general practice in Pennsylvania is to put the underground work in charge of practical men who have been promoted from the ranks. The engineering work is done for a large group of mines by a corps of engineers, who make the necessary surveys and plans for new work, but have little or nothing to do with the executive management.

In other parts of the country the important mines are very generally managed by business men, who leave the underground work largely to their mine-bosses; or else by miners of exceptional business ability, who have been promoted step by step. In such cases the surveying, assaying, and engineering work is done by outsiders,

and a few professional men often do all such work for a large mining district.

The prejudice in favor of the practical man is thus quite general and well founded, but it applies, of course, especially to the recent graduate, and in a very slight degree, or not at all, to the graduate who has been several years engaged in underground work.

The young graduate is deficient in three things which are essential to the man in authority: (1) the art of mining, that is, knowledge of those practical details of mine-work which must be learned underground, and not from lectures or text-books; (2) business experience; (3) the "art of bossing"—executive ability and experience. The first of these we can teach him to some extent in the summer-schools, but the last two he can only gain in positions of responsibility, where he has to exercise discretion in buying and selling, in making contracts and spending money, and in the exercise of authority over men. There is no position about a mine where a young graduate can get this experience without danger of making mistakes in the management of men, or in the management of money, that are likely to be expensive.

There can be no question of the desirability of having our mines managed by educated men, provided they have had practical training as well. Those in charge of our large mining companies, in Pennsylvania for example, apparently have come to the conclusion that they can do without such men. I would raise the question whether this is good policy. Too often the superintendents know little or nothing of engineering, and the members of the engineer corps little or nothing of mining. Under the management of a chief who is both an engineer and a practical miner, the disadvantages of this illogical state of affairs may be reduced to a minimum; but even under such management much money and time are wasted by mistakes in design and construction of plant on the part of the engineers, and by ill-advised mechanical repairs and alterations to the same plant on the part of the practical superintendent. I could cite numerous examples of waste of money, time and material that have come under my own observation due to this lack of co-operation between the executive department and the engineer corps.

Would it not be wise for the large mining companies, who are the parties most interested, to organize some system by which the young graduates of our mining schools can obtain the necessary practical training in the art of mining, in handling men, and in the business office? This need not involve putting these young men into positions of responsibility, but should be rather a system of

practical instruction in subordinate positions in the mine and in the office, in which they can supplement their school training, and become acquainted with the practical details of the art and business of mining in the shortest possible time. It would be possible, of course, to arrange matters so that these young men could do some useful work at the same time and earn a small salary, but this would be at the expense of their practical training and would lengthen the time of their apprenticeship. The men thus trained should be promoted gradually either in the executive department or in the engineer corps, according to their special fitness for one department or the other. Should this plan be adopted, no one should be promoted to a position of responsibility in the engineer corps who has not served a certain number of months or years in some capacity in the mine, and no one should be made a superintendent who has not a good engineering education in addition to his practical training.

The advantages of such a plan are obvious, and, if the details be carefully worked out, there would be no difficulty in carrying it out successfully.

The chief difficulty will be to find the men. But few of the students of our mining schools come from the mining regions, and the reason for this is obvious. Once such a system were organized, and it became generally recognized that the line of promotion lay through the schools, there would be no lack of students.

The schools will gladly co-operate with the mining companies to make this plan a success, and if changes in our course of study seem desirable to fit the young men better for their life-work, such changes will undoubtedly be made. The mining schools have been organized at great expense, and the education of every mining engineer costs the schools many times what they receive in tuition-fees. It seems unfortunate that the advantages thus provided and offered are not utilized as they should be. The responsibility rests, I think, with the mining companies.

Under present conditions, the demand for our graduates far exceeding the supply, the problem of their practical training is much complicated by the ease with which the young graduate finds employment. If he would be content to serve without salary or on a small salary for a year or so, a scheme could be devised by which he could become familiar with underground work, and gradually be entrusted with authority as he proved himself capable of exercising it. But few men, unfortunately, have the courage to resist a tempting position and a good salary, and to take their place among the

workmen. Those of our graduates who have done this have, in almost every case, achieved brilliant success.

Under the circumstances, the best thing we can do would seem to be to develop and expand the summer-school idea, even if we have to curtail somewhat our own vacations to do so. So long as our young graduates are likely to become full-fledged superintendents (or, even worse, "consulting engineers" and "mining experts") as soon as they graduate, so long will it be necessary for us to see that they do not leave the school without some knowledge of underground work.

A few words as to the summer-school of practical mining, as carried on in connection with the School of Mines of Columbia College. The method of instruction has been modified in some important respects since it was described to this Institute some years ago. The salient features of the school, as it exists at present, are:

1. It is a school for observation and study, rather than for manual work. It has been found that, if both are attempted, the more important of the two is apt to suffer.

2. The work is systematic. The plan of giving each student a printed scheme of study is still followed, these schemes being drawn up carefully for each mine visited. Each day a definite subject and a definite part of the mine are assigned to each student for his study.

3. The work of the student is under constant superintendence, and he is carefully taught what to observe and how to record his observations. He is visited at his working-place two or three times a day, and his note-book is examined and marked: 2 (bad), 4 (poor), 6 (fair), 8 (good), 10 (excellent), or 10 + (highly commended). These daily blue-pencil marks of approval or disapproval have a surprising effect on the work of the students. The full success of the summer-school dates from the year when the marking-system was adopted.

4. The students are trained to observe and record details. At first they spend perhaps five days in a drift or gangway, studying the drilling and blasting. The first day they think that they "know it all." The second day they are very much bored at having to see the same thing again. The third day they begin to see that there is something in it that they did not see before, and at the end of the fourth and fifth day they are ready to stay a week longer if it be required.

Usually five weeks are spent at one mine and one week in excursions to other mines. Lately, one week has been given to geological field-work. This will probably be increased.

It is very interesting to observe the effect of this work on the students. They seem sometimes to grow five years older in a single summer. They come to the work boys; they leave it men, fully impressed with the dignity and importance of the work they are doing and of the necessity of preparing themselves for their profession. This little insight into the real work of mining has a wonderful educational effect on them.

I do not know that I agree with Professor Christy in his concluding remarks. I am afraid that if we cannot overcome the prejudice in favor of practical men by the good work our graduates are doing, no amount of governmental influence will help us.

As to the advisability of each school taking up a specialty for which it shall make itself famous, I am inclined to think that this will be more of a personal matter, and will depend on the men who compose the faculty rather than on environment. It will depend also on the demand of and for our graduates. We have always paid a great deal of attention to coal- and iron-mines at the School of Mines, as well as to the methods of the far West, believing that our instruction should be on a broad basis, and that the metal-miner has much to learn of the coal-miner, and vice versa. If we lay a good foundation in mathematics and natural science, and in the special subjects of mineralogy, geology, metallurgy, mining and the different engineering branches, we have not much time left for cultivating any specialty. I believe in making the foundation good, and letting the specialization come after the student leaves the school.

PROF. CHRISTY (Communication to the Secretary): The proof of the above discussion reached me in April, 1894, at a time when I was so occupied with other duties that it has been impossible to make an adequate reply, as I hope to do later.

Concerning Prof. Swain's objections to my estimate that the relative natural fields for mining, civil and mechanical engineers in the United States, are roughly as the numbers 1, 6, and 11, I must now content myself with saying that the objections he has urged were all carefully weighed in making my estimate, and, after going over the ground again very carefully, I do not see that I can change a word I have written under that head. I hope to show later that my estimate is substantially correct. I believe it explains the present tendencies in the growth of engineering schools, and it will appear even more clearly justified in the future.

I heartily agree with Prof. Munroe that "if we cannot overcome the prejudice in favor of practical men by the good work our graduates are doing, no amount of governmental influence will help us."

But if he infers that I look for governmental influence to support the mining schools, he has entirely misapprehended my meaning. Such interference would be, by no means, an unmixed good. It certainly is not to be expected in this country, with the possible exception of some restrictive legislation, such as has long been had with regard to the professions of law and medicine.

I have endeavored to point out, however, how we are forced, by the absence in this country of that close relation between the government, the mines, and the mining schools which exists in certain continental countries, to depend for co-operation on the good-will and even caprice of individual mining companies, organized on widely different plans. Abroad, this co-operation is secured through one central source of power; the mining school and the mine are parts of the same system and work in harmony. The only examples we have of this relation in America are the government schools at West Point and Annapolis; and the good that there results from an official connection between the theory and the practice of the art of war must be admitted.

I have long been convinced of the advantages that would result to the mine-owners, as well as the mining schools, if it were possible to organize some such system as that mentioned by Prof. Munroe, by which graduates of the mining schools would be allowed to serve an apprenticeship in the art of handling men and in executive work generally, with the understanding that their promotion depended entirely on their efficiency. In all cases where I have been able to effect such an experiment, the results have been eminently satisfactory to all concerned. If the government owned or controlled the working of the mines, the general introduction of such a system would be a very simple matter.

"But," as I have already said in my paper,

> "It is so foreign to our national tendencies that it is improbable that our mining schools will ever receive the backing that comes from the government control and ownership of mines. Nevertheless, there is such an inherent force in earnest convictions that even without it much may be accomplished by the co-operation of those who think and feel alike. The brilliant success of the American Institute of Mining Engineers is an example of what may be accomplished by private action. No law holds it together, yet few governments have done more to elevate the profession than this Society.
>
> "If half-a-dozen of the most active of our mining schools were to take common ground on some of these questions, and were to receive the hearty backing of the leading mining engineers and mine-owners of the country, much could be done to establish, in fact, the bond of union between the mine and the mining school which in America does not exist in law."

INDEX.

[NOTE.—In this Index authors' names are printed in small capitals and the titles of papers in italics. Casual references, giving but little information, are usually indicated by bracketed page-numbers.]

ERRATUM.

On page 193, line 7 from the bottom, ".0019" (the conductivity of wrought-iron at 0°) should read "0.019."

Abel, Sir F., on hardening of steel, 157, 190.
Air-compressors, electric, 404.
Air-currents in mine gangways, measurement of, 63 *et seq.*
Air-thermometers, 408 *et seq.*
Alabama Polytechnic Institute, number of mining-students graduated from, 445.
Alford, C. A., on geology of the Transvaal [345].
Alloys (see also the metals): pyrometric, 430; record of cooling of copper-tin, 442.
Almás gold-mine, Dacian district, Transylvania, 275.
Alsace, Germany, iron-ore deposits, 321.
Alte Hoffnung Erbstollen silver-mine. Mitweida, Saxony, character of ground-water at, 222.
Aluminum, effect of air on [155].
Aluminum-steel, analyses of, 196.
Amador county, Cal., stamp-mills of, 551.
Amalgamating-tables for stamp-mills, 143.
Åmmeberg, Sweden, zinc-blende mine at, 326.
Analyses of: Boiler-plate, 630, 631.
Car-axles, 632.
Car-wheels, 621.
Cast-steel, 158.
Clay-slate from Styrian *Erzberg*, Austria, 24.
Coal: Lignite from Styria, Austria, 33; from Rock Springs, Wyoming, 135.
Coke: from Silesia, Austria, 24; from Colorado, 580.
Gas: furnace-gas, 29 *et seq.*; gas liberated from warm mineral water, 228.
Iron: 615, 617; iron prepared from Swedish bar, 148.
Iron-ores: from Styrian *Erzberg*, Austria, 24 *et seq*; from Colorado, 580.
Limestone from Colorado, 580.
Metallic sulphides from fissure veins, 230.
Mineral waters, 234.
Pig-iron, 580; Pottstown Iron Company's, 582 *et seq.*
Slag in new process for production of pig-iron, 25.
Spring-water and ice, 611, 612.

Analyses of (*continued*):
Steel: aluminum-, chromium-, manganese- and silicon-steel, 196; ring casting from Hecla Works, Sheffield, England, 612; determining absorption of sulphur, 624; structural, 621; tool-steel, 158.
Waters encountered in mines, 234.
Ancient tablet, inscription on, 156.
Andreasberg, Hartz mountains, silver-ore veins of, 270.
Anemometer, Casartelli's, for measuring loss of head of air-currents in mines, 74.
Antimony, effect of air on [155].
Apparatus for measuring loss of head of air-currents in mines, 68 *et seq.*
ARGALL, PHILIP, remarks in discussion of Mr. Rickard's paper on the gold stamp-mill, 554.
Arizona, copper-deposits of, 316.
Arlesey Cement Co., near London, England, 171.
Arnold, Prof., preparation of almost pure iron by, 148.
Ascending waters: carbonic acid the most important geological factor, 237; encountered in mines, 222; heat of, 224 *et seq.*; hydrogen sulphide in, 236; precipitation from, 263.
Aurora silver-mines, Esmeralda county, Nev. [298].
AUSTIN, W. L., remarks in discussion of Mr. Rickard's paper on the gold stamp-mill, 573.
Australasia, gold-deposits of, 344.
Australia, stamp-mills of, 143, 554, 557, 561 *et seq.*
Axles of manganese-steel, 183.
A Y silver-mine, Iron Hill, Lake county, Colo., 602.

Baltimore and Ohio Railroad Co., electric locomotives used by, 403.
Barker, G., tests of forged manganese-steel by, 177.
Barnaby, J. F., tensile tests of forged manganese-steel by, 177.
Barrett, Prof.: on electrical conductivity of steel, 194; on peculiarities of manganese-steel, 191.
Barus, Prof. Carl: on advances in pyrometry, 407 *et seq.*; pyrometrical method of, 437.
Bavarian Lead-Mining Co., 314.
Beaumont, Elie de, theory of "pentagonal symmetry" of [203].
BECKER, G. F.: remarks in discussion of Prof. Posepný's paper on the genesis of ore-deposits, 602; on temperature of underground workings, 224.
Becquerel César, contributions to electro-pyrometry by, 411.
Becquerel, Edmond, experiments in pyrometry by, 412.
Belcher silver-mine, Storey county, Nev. [280].
Belgium, calamine-deposits of, 319.
Bell, Charles, on heat-measurements, 423.
Bell, R., on ore-deposits of Sudbury, Can., 329.
Benyes silver-lead-mine, Rodna, Transylvania, 286.
BERGENDAL, T., remarks in discussion of physics of steel, 620.
Bescheert Glück silver-mine, Freiberg, Saxony, 268.
Bessèges coal-mines, Gard, France, measurement of air-currents in gangways of, 76 *et seq.*
Bessemer converter, measurement of temperature of, by optical pyrometer, 437.
Bessemer metal, microstructure of, 48 *et seq.*
Beta-iron theory, 149, 189.
Bethlehem Iron Co., South Bethlehem, Pa., forging of manganese-steel by, 165.
Bischof on metallic deposits from sea-water, 307.
Bish lead-mine, St. François county, Mo. [302].
Black Hawk, Gilpin county, Colo., stamp-mills, 548, 558, 572.

Black Hills, So. Dak., gold-milling in [550].
BLACKWELL, F. O.: *Electricity in Mining* [lxxxvi], 399.
Blake crushers, manganese-steel for cheeks of, 171.
Blake pump worked by electric motor, 404.
BLAKE, W. P.: remarks in discussion of Prof. Pošepný's paper on the genesis of ore-deposits, 587; on ore-deposits in Copper Basin, Arizona, 317.
Blass, E., experiments in pyrometry by, 441.
Blast-furnace practice: anthracite-practice, 379; appliances for recording temperature, 423 *et seq.*; blowing-in, old manner of, 370; charcoal furnaces, 379; chimneys, number of, 380; "direct-metal" process, 374; durability of lining, 373, 381; fuels and ores of the United States, 379; "mixer," devised by Capt. Jones, 375; review of American, 370, 577.
Blast-furnaces: *Colorado:* Pueblo; Colorado Fuel and Iron Co., 577 *et seq.*; *Illinois:* Cook county; North Chicago Rolling-Mill Co., South Chicago Works, 372 *et seq.*; *New York:* Oneida county; Franklin [379]; *Pennsylvania:* Allegheny county; Edgar Thomson, 370 *et seq.*; Bucks county; Durham [379]; Lehigh county; Thomas [379]; Montgomery county; Warwick [379]; *Wisconsin:* Ashland county; Hinkle, 379; Milwaukee county: Milwaukee, No. 2 (Illinois Steel Co.), 374.
BLAUVELT, W. H., remarks in discussion of Mr. Stetefeldt's paper on consumption of fuel at Aspen and Marsac mills compared, 585.
Blowing-engines of Colorado Fuel and Iron Co., 578.
Blowing-in: of Edgar Thomson A furnace in 1879, 371; old American practice, 370.
Bobierre, A., amount of salt in rain-water found by, 236.
Bohemia: ancient gold-workings in Trautenau region, 345; copper-sandstones of, 312; *kupferschiefer* of, 309; ore-deposits at Przibram, 252 *et seq.*, 272; temperature of thermal springs, 233; tin-placers at Platten [342].
Bohneisenerze, deposits of, 321.
Boiler-plate, analyses and tests of, 629 *et seq.*
Boitza gold-mine, Dacian district, Transylvania, 275.
Botesin gold-mine, Dacian district, Transylvania, 277.
Braun-Hartmann electrical-resistance pyrometer, 441.
Breece iron-ore, Colo., 577; analysis of, 580.
Brennthal iron-mine, near Mühlbach, Switzerland [327].
Britannia stamp-mill, Ballarat, Victoria, cost of milling at, 567.
Brittleness of manganese-steel, cause of, 160.
Brown-Bayley's Steel Works, Sheffield, England, tensile tests of forged manganese-steel at, 177, 184, 185.

Calamine-deposits, 318.
California: copper-ores in peninsula of Lower, 317; gold stamp-mills of, 137 *et seq.*
California gold-mine, Gilpin county, Colo. [545].
California silver-mine, Storey county, Nev., 280.
California stamp-mills, 138 *et seq.*, 550 *et seq.*
California University, Berkeley, Cal., number of graduates from, 445.
Callendar pyrometer, 417.
Calumet and Hecla copper-mine, Lake Superior district, Mich., 328; use of electric power at, 401.
Calumet iron-ore, Colo., 577; analysis of, 580.
CAMPBELL, PROF. E. D., remarks in discussion of physics of steel, 620.
Canada, ore-deposits of Sudbury, 329, 607.
Car-axles, analyses of, 632.
Carbon: action of, upon iron, 150, 152, 156; in cast-iron, 156; influence of, on steel, 113 *et seq.*
Carbonic acid an important geological factor in ascending waters, 237.

Carbon-steel: critical points of, 476; specific gravity, 195; water-quenched hardness of, 152.
Carbon theory of hardening steel, 495 *et seq.*
Carinthia: calamine-deposits of Raibl, 318; ore-deposits of, 289; ore-veins at Raibl, 252 *et seq.*
Carlsbad *Sprudel:* analysis and temperature of water, 233, 234; character of deposit, 245.
Carniola, Wochein, iron-ore deposits, 321.
Car-wheels: analysis of, 621; of manganese-steel, 173.
Casartelli's anemometer, 74.
Cast-iron: carbon in, 156; effect of "chilling," 157; sulphur in, 382.
Cast manganese-steel, condition of strength of, 160.
Cavities in rocks, character of, 207.
CAZIN, F. M. F.: remarks in discussion of Prof. Posepný's paper on the genesis of ore-deposits, 604; on copper-ores of New Mexico, 316.
Charcoal-furnace, record of Hinkle, Ashland, Wis, 379.
Chemical constitution of mineral waters, 232 *et seq.*
Chilian mills [555].
Chollar Mining Co.'s silver-mine, Comstock Lode, Virginia City, Nev., electrical power at, 401.
CHRISTY, SAMUEL B.: *The Growth of American Mining-Schools and their Relation to the Mining Industry* [lxxxv], 444; discussion, 657; Prof. Christy, in discussion of his paper, 665.
Chromium-steel, analyses of, 196.
CHURCH, JOHN A.: remarks in discussion of Prof. Posepný's paper on the genesis of ore-deposits, 593; on source of underground waters, 225.
Churprinz silver-mine, Freiberg, Saxony, ascending mineral waters at, 222, 267.
Clarence iron-works, Cleveland district, England, use of Le Chatelier pyrometer at, 423.
Classification of ore-deposits, systems employed hitherto, 199.
Clausthal, Hartz mountains, character of ore-veins at, 269.
Clay-slate, analysis of, 24.
Cinnabar in decomposed basalt, filling rock-fissures at Sulphur Bank, Cal., 225.
Coal: analyses of, 135; *Alabama:* Jefferson county; Newcastle, 135; *Colorado:* Garfield county; Sunshine, 135; *Utah:* Summit county; Coalville, 136; *Wyoming:* Sweetwater county; Rock Springs, 134 *et seq.*
Coal-basin, Saarbrücken, 305.
Coal-cutting, electric, 405.
Coal-fields of Manvers Main Colliery Co., South Yorkshire, England [172].
Coal-mines: *Bohemia:* Dux (lignite), 223; *England:* South Yorkshire; Thorncliffe, 176; *France:* Ceréal, 81 *et seq.;* Gard; Bessèges, 76 *et seq.;* Montrambert, 79.
Coalville coal, Summit county, Utah, 136.
Cohen, E., on Witwatersrand gold-deposits, South Africa, 344.
Coke: analysis of Silesian, 24; of Southern Colorado, 577; analysis of, 580.
Colliery-Engineer "Correspondence of School of Mines," 459.
Colorado: gold stamp-mills of, 137 *et seq.;* ore-deposits of Leadville, 293; Red Mountain district, Ouray county, character of ore-deposits, 296.
Colorado Fuel and Iron Co., Pueblo, Colo., blast-furnace practice of, 577.
Colorado School of Mines, Golden, Colo., number of graduates from, 445.
Colorado stamp-mills, 137 *et seq.*, 545 *et seq.*
Columbia School of Mines, New York City, founding of, 444; number of graduates from, 445.
Comstock Lode, Storey county, Nev.: geological conditions of, 278; heat of ascending waters at, 224; ore-deposition, 593.
Conductivity: electrical, of manganese-steel, 194; thermal, of manganese-steel, 192.

Conical mounds and chimneys built by ascending mineral waters, 231.
Consolidated Virginia silver-mine, Storey county, Nev., 280.
Consumption of Fuel in the Taylor Gas-Producer Plants at the Aspen and Marsac Mills Compared (STETEFELDT) [lxxxvii], 134; discussion, 585.
Contraction of manganese-steel, 194.
Copper-deposits of New Mexico and Arizona, 316.
Copper, effect of heat on tensile properties of, 534.
Copper Falls copper-mine, Lake Superior district, Mich., 328.
Copper-mines: *Michigan:* Houghton county; Calumet and Hecla, 328 [401]; Keweenaw county; Copper Falls, 328; Ontonagon county; Nonesuch [329]; *Vermont:* Orange county; Strafford [605]; Vermont, 604; Windsor county; Pompanoosuc [605]; *Tyrol:* Prettau, 327.
Copper-ores; of Falun, Sweden, 325; in Germany and Bohemia, 309; of Lake Superior district, 328; in lower California, 317; of New Mexico, 607; of Sudbury, Can., 607; of Vermont, 604.
Copper-sandstones of Bohemia, 312.
Copper-tin alloy, record of cooling of, 442.
Cornwall, England, tin-deposits of, 323.
Cost of milling in gold stamp-mills, 144, 553, 567.
Cotta: classification of ore-deposits by, 209; on ore-deposition, 309.
Créal coal-mine, France, experiments determining loss of head of air-currents at, 81 *et seq.*
Creusot iron-works, France [430].
Crova, spectro-pyrometer of, at Creusot iron-works, 430.
"Crustification" a feature of mineral deposits in cavities, 207.
Cumberland, England, iron-ore deposits, 321.
CUNNINGHAM, A. C., remarks in discussion of physics of steel, 626.

Dacian gold-fields, Transylvania, 275.
Daly silver-mine, Summit county, Utah [135].
Daubrée, Prof. A.: on action of mineral waters upon rock, 240; on subterranean water-circulation [212], 221.
Deadwood Terra stamp-mill, Black Hills, So. Dak., cost of milling at, 553.
Deaths of members and associates, lix.
Decomposition of different metals, 333.
Deep underground circulation, 220.
Deprez and D'Arsonval galvanometer, 418.
Devereux, W. B., on occurrence of gold in the Black Hills, So. Dakota [343].
Deville and Troost on porcelain-bulb air-thermometers, 413.
Devillez on the ventilation of mines, 65 *et seq.*
Diamond-drills, electric, 404.
Diffusion of sulphides and phosphides through iron and steel, experiments on, 621 *et seq.*
"Direct-metal" process, effect of, on operations of blast-furnace, 374.
Discission, spaces of, 208, 264.
Dissolution, spaces of, 208.
Dodge ore-crusher [547].
Dredger-pins of manganese-steel, 165; wear of, 167.
Dressing-works (see also stamp-mills): *Colorado:* Gilpin county; Black Hawk, 548.
Drilling, electric, 404.
Drop tests of forged manganese-steel, 176.
DROWN, PROF. T. M., remarks in discussion of physics of steel, 610.
DUDLEY, P. H., remarks in discussion of physics of steel, 647; on hardness and toughness of manganese-steel, 186.

Durham blast-furnace, Riegelsville, Pa. [379].
Dux coal-mine (lignite), Bohemia, irruption of thermal waters at, 223.

East Wheal Lovell t. -mine, Cornwall, England, 324.
Eberhardt silver-mine, White Pine county, Nev., 298.
Edgar Thomson blast-furnace, Pittsburgh, Pa., 371 *et seq.*
Egleston, Prof. T., on hammering gold, 556.
Einigkeit silver-mine, Joachimsthal, Saxony, ascending mineral springs at, 223, 233.
El Callao stamp-mill, Caratal, Venezuela, cost of milling at, 553, 567.
Electric air-compressors, 404.
Electrical characteristics of manganese-steel, 186.
Electrical conductivity of manganese-steel, 194.
Electric coal-cutting, 405.
Electric drilling, 404.
Electric generators, 401.
Electric haulage, 402.
Electric hoisting, 403; at Brooklyn docks of Wilson Steamship Co., 403.
Electricity in Mining (BLACKWELL) [lxxxvi], 399.
Electric lighting, 406.
Electric locomotives, 403.
Electric power: advantage of, in mining, 400; transmission and distribution, 401.
Electric pumping, 404.
Electro-metallurgy, 406.
Emma silver-lead-mine, Salt Lake county, Utah [297].
Emmens, S. H., on decomposition of metals, 333.
EMMONS, S. F., remarks in discussion of Prof. Posepný's paper on the genesis of ore-deposits, 597.
Engineers, normal relative demand for, in the United States, 447, 449.
England: iron-ores of Cumberland, 321; lead-mining in north of, 292.
Erbsenstein, deposits of, at Carlsbad, 245.
Erzgebirge, mineral springs in mines of, 222 *et seq.*; ore-deposits in, 271.
Eureka-Richmond case [298].
Eureka silver-lead-mine, Eureka county, Nev., 298, 300.
Ewing, Prof., on magnetic induction of manganese-steel, 191.
Excelsior stamp-mill, Charters Towers, Queensland, cost of milling at, 567.
Experimental Investigations on the "Loss of Head" of Air-Currents in Underground Workings (MURGUE) [lxxxv], 63.

Faczebaja gold-mine, Dacian district, Transylvania, 275.
Ferro-manganese, first commercial production of, 159.
Fissures: of dislocation, 209; ore-deposits in, 264.
Flagstaff silver-lead-mine, Salt Lake county, Utah [297].
Forged manganese-steel: qualities of, 162; tenacity per square inch, 178; tests of, 176.
Foster, C. Le Neve, on tin-deposits of Cornwall, 323.
Foullon, A. B. von, on ore-deposits of Sudbury, Can., 329.
France, sandstone at Fontainebleau, 305.
Franklin blast-furnace, Oneida county, N. Y. [379].
Freihung, Bavarian Upper Palatinate, lead-deposits, 314.
Fuchs, E., on copper-ores of Lower California, 317.
Fuel: consumption in Taylor gas-producer plants, 134, 585; experiments in economy in, at South Chicago blast-furnaces, 372; gas in new process for production of pig-iron, etc., 4.
Füzesd gold-mine, Dacian district, Transylvania, 275, 278.

Furnaces: Hoskins muffle [623]; for production of pig-iron, by new process, 8 *et seq.*; Siemens-Martin open-hearth, 437; Siemens, for melting glass, 437; Stetefeldt, 134, 585; tube-muffle, 535; at Woolwich Arsenal, England [436].

Further Observations on the Relations Between the Chemical Constitution and Physical Character of Steel (WEBSTER) [lxxxvii], 113; for discussion see "Physics of Steel," 608.

Gage, J. R., on occurrence of lead- and zinc-ores in Missouri, 302.

Galvanometers: Deprez and D'Arsonval, 418 [467]; Sturgeon, 415; value of, in pyrometry, 442.

Gangways, experiments determining loss of head of air-currents in underground, 82 *et seq.*

Garden Gully United Stamp-mill, Bendigo, Victoria, 568.

Gases: analysis of furnace, 29 *et seq.*; analysis of, liberated from warm mineral waters, 228; as fuel in new process for production of pig-iron, 4; temperature of, measured by optical pyrometer, 436, 437; Waterson on kinetic theory of, 413.

Gas-furnace for production of pig-iron, 8 *et seq.*

Gas-producers: Taylor, 134 *et seq.*, 587; Wellman, 587.

Geber, ancient treatise on furnaces by, 407.

General Electric Co., Schenectady works of [403].

Genesis of Ore-Deposits (POŠEPNÝ) [lxxxv], 197; discussion, 587.

Geodes, opal and chalcedony, mineral deposits in, 218.

Germany: calamine-deposits, 319; lead-deposits of Mechernich, near Commern, 313; tin-placers at Annaberg, Saxony [342].

"Glass-scratching" hardness of iron, 153.

GOETZ, GEORGE W., remarks in discussion of Mr. Stetefeldt's paper on consumption of fuel at Aspen and Marsac mills compared, 587.

Gold: ancient placer-mining in Bohemia, 345; deposits of Australasia, 344; deposits at Bessèges, France, 345; deposits of Black Hills, So. Dak., 343; melting temperature at Royal Mint, London, England, 436; occurrence of, in manganese spar, 258; placer-deposits of Ural Mountains, 337, 339; in the Ural Mountains [266].

Gold-fields: *South Africa:* Witwatersrand, 344; *Transylvania:* Dacian, 275.

Gold Hill silver-mine, Storey county, Nev. [224].

Gold-mines: UNITED STATES: *California:* Amador county, Spanish [553]; *Colorado:* Gilpin county, California [545]. OTHER COUNTRIES: *Brazil:* Morro Velho, 554; *Transylvania:* Dacian gold-district, 275; Verespatak, Katrontza, 256; Mátyas Kiraly, 258, 261.

Gold-ores at Falun, Sweden, 325.

Gold stamp-mills (see also stamp-mills): analogy to hammer and anvil, 137, 141; of California and Colorado, 137 *et seq.*, 545 *et. seq.*; cost of milling in, 144, 553, 567; efficiency of stamp, 138; evolution of, 145; speed, 138; at Verespatak, Transylvania, 145; weight of stamp, 138 *et seq.*; yield per ton of ore, 144.

Gottes Geschick silver-mine, Schwarzenburg, Saxony, ascending waters at, 222, 223.

Gover stamp-mill. Amador, Cal., cost of milling at, 567, 568, 570.

Graduates of American mining-schools: annual openings for, 453; number of, in 26 years, 445.

Greece, mining regions of, 319.

Greene-Wahl process for manufacturing manganese [153].

Grimm, J.: classification of ore-deposits by, 200; examination of Transylvania ore-deposits by, 284.

Groddeck, A. von: on ore-deposition, 308 *et seq*; system of classification of ore-deposits by, 200.

Ground-water, movements of, 213.

Growth of American Mining-Schools and their Relation to the Mining Industry (CHRISTY) [lxxxv], 444; discussion, p. 657.

HADFIELD, R. A.: *Iron Alloys with Special Reference to Manganese Steel* [lxxxvii], 148; remarks in discussion of physics of steel, 612.
Hadfield Steel Foundry Co., Sheffield, England, 165; comparison of contraction of manganese steel at, 194.
Hale and Norcross silver-mine, Comstock Lode, Nev. [224].
Hardening, effect of, on steel, 149 *et seq.*
Hardening-power of steel, 495 *et seq.*
Hardness of manganese-steel, 163 *et seq.*
Hardness of steel of varying composition, Turner's table of, 196.
Harrietville stamp-mill, Ovens, Victoria, 568.
Haulage, electric, 402.
Heat, effect of: on tensile properties of copper, 534; on tensile properties of steel, 532.
Heat-Treatment of Steel (HOWE) [lxxxvii], 466; for discussion see "Physics of Steel," 608.
Hecla Steel-works, Sheffield, England, 159 *et seq.* [612]; tests of manganese-steel car-wheels at, 174.
Helmhacker, R., on ore-deposits of Altai region, Siberia [338].
HIBBARD, HENRY D., remarks in discussion of physics of steel, 625.
Hidden Treasure silver-mine, Juab county, Utah [297], 298.
Hidden-Treasure stamp-mill, Gilpin county, Colo., 545, 567, 568.
Hinkle blast-furnace, Ashland, Wis., 379.
Hoefer, H., on metallic deposits from sea-water, 307.
Hoisting, electric, 403.
Holden Smelting and Milling Co., Aspen, Colo., lixiviation-works of, 134, 585.
HOMATSCH, ANTON, and SATTMAN, ALEXANDER: *A New Process for the Production of Pig-Iron, Refined Iron, Ingot Metal and Weld-Metal* [lxxxvii], 3.
Homestake stamp-mill, Black Hills, So. Dak., cost of milling at, 553.
Hopkinson, Dr., on magnetic property of iron affected by manganese, 160.
Hoskins muffle-furnace [623].
Hot mineral waters encountered in mines, 223 *et seq.*
HOWE, H. M.: *The Heat-Treatment of Steel* [lxxxvii], 466: for discussion see "Physics of Steel," 608; remarks in discussion of physics of steel, 655: on crystallization of iron by vibration, 576.
Hungarian stamp-mill [555].
Hungary: geode of iron opal from Dreiwasser, 218; ore-deposits of, 274; silver-deposits of Rézbánya, 286.
Huntington stamp-mill [553].
Hydrogen sulphide, important part of, in ascending waters, 236.
Hysterogenites, 211.
Hysteromorphous ore-deposits, 331.

Ice, analyses of, 611, 612.
Idiogenous mineral deposits, 205.
Idria quicksilver-mine, Austria, 457,
Illinois Steel Co., Milwaukee No. 2 blast-furnace of, Milwaukee, Wis., 374.
Illinois University, Champaign, Ill., number of mining-students graduated from, 445.
Ingot-iron, manner of investigating structure of, 42; microstructure of, 37 *et seq.*
Ingot-metal, new process for production of, 3.
Intramural electric railway, World's Fair, Chicago, electric generators for, 401.

Iron (see also ingot-iron, pig-iron, etc.): allotropic β-state of, 520 *et seq.*; allotropic modifications of, 153; analysis of, 615, 617; "Beta" theory, 149, 189; effect of carbon on, 150 *et seq.*; effect of silicon on, 151; "glass-scratching" hardness of, 153; graphitic and combined forms, 157; magnetic property affected by manganese, 160; melting of carburized iron sponge in new process for production of pig-iron, 6; new process for production of refined, 3; oldest pieces of "wrought-iron" in existence, 156; stratification of cast-, 615 *et seq.*; sulphur in cast-, 382; tenacity of pure, 149; theory of crystallization of, by vibration, 560, 573.

Iron Alloys with Special Reference to Manganese Steel (HADFIELD) [lxxxvii], 148.

Iron Hill, Lake county, Colo., silver-mines of, 602.

Iron-mines: *Norway:* Röras; Kongens [325]; Troudhjem; [325]; *Switzerland:* Brennthal (near Mühlbach) [327].

Iron opal, geode of, from Dreiwasser, Hungary, 218.

Iron-ores: analyses of, 24 *et seq.*; *Colorado:* Breece (red hematite), 577; Calumet (magnetite), 577; Morning Glory (red hematite), 577; Orient (brown hematite), 577; *Minnesota:* Vermilion [577]; *England:* Cumberland, 321; *Germany:* Alsace, 321; *Spain:* Rio Tinto (limonite), 332; *Sweden:* Taberg (magnetite), 322; *Switzerland:* Carniola, 321.

Iron-works: *New Jersey:* Hunterdon county; Taylor Iron and Steel [476]; *Pennsylvania:* Northampton county; Bethlehem Iron Co. [165]; *England:* Cleveland district; Clarence, 423; *France:* Creusot [430]; Terre Noire [159].

Jones, Capt. W. R., "mixer" devised by, 375.

Jumpers stamp-mill, Johannesburg, So. Africa, cost of milling at, 567.

Justice silver-mine, Storey county, Nev., 280.

Kackar district, southern Ural, Russia, 339.

Kapnik mining district, Hungary, 275.

Katrontza gold-mine, Verespatak, Transylvania, 256.

KEEP, W. J.: *Sulphur in Cast-Iron* [lxxxvii], 382; remarks in discussion of physics of steel, 615; tests for cast-iron, 384.

Kendall, J. D., on iron-ores of Cumberland, England, 321.

Kennedy, Prof., tests of forged manganese-steel by, 177, 178.

KENT, R., remarks in discussion of physics of steel, 632.

Kerr, W. C., on North Carolina gold-deposits [336, 338].

Keystone stamp-mill, Amador county, Cal., cost of milling at, 553.

Kirkaldy, David: tests of forged manganese-steel by, 177, 179; tests relating to specific gravity of manganese-steel by, 195.

Kjerulf, Th., on iron-ore deposits in Norway [323], 324.

Kongens iron-mine, Röras, Norway [325].

Kunhardt, W. B.: paper by Martens translated by, 37; paper by Sattmann and Homatsch translated by, 3.

Kupferschiefer of Mansfeld, Thuringia and Bohemia, 309.

Lafayette College, Easton, Pa., number of mining-students graduated from, 445.

Lake Superior copper-deposits, 328.

Lapparent, A. de, on metamorphism, 304.

Lateral-secretion theory of ore-deposition, 248 *et seq.*, 589, 597 *et seq.*

Launay, de, chemical classification of ore-deposits by, 203, 206.

Laurium silver-lead-mines, Greece, 319.

Lawrence centrifugal pump worked by electric motor, 404.

Lead in mineral-springs, 239.

Lead-deposits: of Freihung, Bavarian Upper Palatinate, 314; of Mechernich, near Commern, Germany, 314.

Lead-mines (see also silver-lead mines): *Missouri:* Jefferson county; Vallé, 261, 302; St. François county; Bish [302]: *England:* 292; *Germany:* Bavaria; Vesuvius, 314.
Lead-regions of Missouri and Wisconsin, 301.
Leadville, Colo., ore-deposits, 293.
Le Chatelier, Prof. H.: on electrical conductivity of steel, 194; photometric instrument of, 431; on the platinum-rhodium thermo-couple, 416; pyrometer of, 418; thermo-electric couple [467].
Le Conte, J., on mineral vein-formations, 226.
Ledebur, Prof. A., on forms of carbon in iron and steel, 150, 157, 158, 190.
Lehigh University, Bethlehem, Pa., number of mining-students graduated from, 445.
Lehigh and Wilkesbarre Coal Co., manganese-steel wheels for mining-wagons, used by, 175.
Lignite (see also coal), analysis of, 33.
Limestone: analysis of, 580; lead-deposits in Carboniferous, in England, 292; ore-bearing, in Carinthia, 289; ore-deposits in, 284 *et seq.*
Limestone caves, mineral deposits in, 218.
Limitations of the Gold Stamp-Mill (RICKARD), [lxxxvi], 137; discussion, 545.
Lixiviation-works (see also stamp-mills): *Colorado:* Aspen: Holden Smelting and Milling Co., 134, 585.
Lock, A. G., on gold-deposits, 336, 338.
Locomotives, electric, 403.
Long-distance transmission of electric power, 401.
"Loss of Head," analytical explanation of, 63.
Loss of Head of air-currents: appliances for testing, 67; description of method of observation in mine-gangways, 67; experiments in underground gangways, 82 *et seq.*; ratio of to the square of average velocity, 79; in underground workings, 63.
Lottner, classification of ore-deposits by, 202.

Machinery, crushing- and grinding-, of manganese-steel, 169.
Magura gold-mine, Dacian district, Transylvania, 275, 278.
Manganese: characteristics of, 153; Greene-Wahl process for manufacturing [153]; influence of, on steel, 114 *et seq.*
Manganese-steel: 148 *et seq.*, 159; for agricultural implements, 172; analyses of, 196; axles, 183; cast, 160; cause of brittleness, 160; for cheeks of Blake crushers, 171; contraction of, 194; for crushing- and grinding-machinery, 169; discovery of, at Hecla works, Sheffield, England, 160; dredger-pins, 165 *et seq.*; effect of sudden cooling on, 467 *et seq.*; for electrical resistance work, 191; elevator-links of, 171; explanation of toughness and resistance to fracture of cast, 161; forged, 162; hardness of, 163 *et seq.*; low tenacity of cast, 162; non-magnetic character of, 186; rings of, compared with best cast-iron rings, 171; specific gravity, 195; tests of, 160 *et seq.*; tests of car-wheels, 173; tests of forged, 176; thermal and electrical conductivity and specific heat of, 192; tires, 185; uses of, 163; for wheels, 173.
Manner of filling open spaces with ore-bearing deposits, 255.
Mansfeld *kupferschiefer*, 309.
Manvers Main Colliery Co., South Yorkshire, England [172].
Marsac stamp-mill, Park City, Utah, 134, 585.
MARTENS, A.: *The Microstructure of Ingot-Iron in Cast Ingots* [lxxxvi], 37; for discussion see "Physics of Steel," 608.
Massachusetts Institute of Technology, Boston, Mass., graduation of mining students at, 444, 445; mining laboratory at, 460.
Matyas Kiraly gold-mine, Verespatak, Transylvania, 258, 261.

May consolidated stamp-mill, Johannesburg, So. Africa, cost of milling at, 567.
MAYNARD, PROF. G. W., remarks in discussion of Prof. Christy's paper on American mining schools, 657.
Meetings of the Institute, list of, lxxvi.
Members and Associates, names and addresses of, x.
Metallography, microscopic, 37 *et seq.*
Metallurgy, electrical processes, 406.
Metamorphous ore-deposits, 304 *et seq.*
Metasomatic ore-deposits in soluble rocks, 318.
Metcalf, W.: on specific gravity of carbon-steel, 195; on treatment of steel [155].
Michigan Mining School, Houghton, Mich., number of graduates from, 445.
Microscopic metallography, 37 *et seq.*
Microstructure: of Bessemer metal, 48 *et seq.*; of open-hearth metal, 52; of Thomas metal, 49 *et seq.*
Microstructure of Ingot-Iron in Cast Ingots(MARTENS) [lxxxvi], 37; for discussion see "Physics of Steel," 608.
Milling: comparison of results between smelting and milling gold- and silver-ore, 546; cost of milling gold in stamp-mills, 144, 553, 567; gold- and silver-ore at Black Hawk stamp-mills, Col., 548, 558; gold- and silver-ore at Hidden Treasure stamp-mill, Col., 546.
Milwaukee No. 2 blast-furnace, Milwaukee, Wis., Illinois Steel Co.'s, record of, 374.
Mine La Motte, Madison county, Mo., lead-deposits at, 303.
Mineral deposits: geodes, 218; idiogenous and xenogenous, 205 *et seq.*; in limestone caves, 218.
Mineral industry of the United States, personnel of (from Eleventh Census), 450.
Mineral products of the United States for 1880 and 1891, 447.
Mineral springs: structural features of deposits of, 244; at the surface, 230.
Mineral-waters: alterations produced by, 240; analyses of, 229, 234; chemical constitution of, 232; effect of, upon artificial products immersed in them, 242; minute metallic admixtures in, 238; temperature of, 233.
Mines, lighting and ventilation of, by electric power, 406.
Mining: advantages of electric power in, 400; rock-salt at Máros Ujáva, Transylvania, 215.
Mining laboratory at Mass. Institute of Technology, organized by Prof. Richards, 460.
Mining and metallurgy, number of those engaged in, in the United States, 448 *et seq.*
Mining-schools: American, total number of graduates from, 445; are they justified? 453; attendance at American and European, 455; difficulties peculiar to American, 407; future of American, 460; graduates from American, in 26 years, 444; growth of American, 444; mining laboratory at Mass. Institute of Technology, 460; right to confer degree, 464; suggestions for manner of study, 463; summer school, 461.
Minnie silver-mine, Iron Hill, Lake county, Colo., 602.
Missouri, lead-regions of, 301, 588.
Missouri University, Rolla, Mo., number of mining-students graduated from, 445.
Mitchell, Dr. A. C., on manganese-steel, 192; on thermal conductivity of iron, copper and German silver, 193.
Montana school of mines, number of graduates from, 445.
Montrambert collieries, France, experiments determining loss of head of air-currents at, 79.
Morgan stamp-mill, South Wales, cost of milling at, 567.
Morning glory iron-ore, Colo., 577; analysis of, 580.
MORRIS, W. H., remarks in discussion of Mr. Potter's paper on American blast-furnace practice, 581.
Morro Velho gold-mines, Brazil, S. A., stamp-mill at, 554.

Mortars for gold stamp-mills, 140, 551, *et seq.*
Mountain stamp-mill, Thames, New Zealand, cost of milling at, 567.
Müller, H., on mineral springs, 222.
Muffle-furnace, Hoskins [623].
Mug iron-mine, Trondhjem, Norway [325].
MUNROE, PROF. H. S.: remarks in discussion of Prof. Christy's paper on American mining schools, 659; organization of summer school of mining by, 461.
MURGUE, D.: *Experimental Investigations on the "Loss of Head" of Air-Currents in Underground Workings* [lxxxv], 63.
Musschenbroek pyrometer, 410.
Mysore stamp-mill, Kolar, India, cost of milling at, 567.

Nagyag gold-mine, Dacian district, Transylvania, 275, 278.
Nash, T., result of tensile tests of forged manganese-steel, by, 177.
Natural gas in new process for production of pig-iron, 4.
Nevada, character of ore-deposits in, 297.
Newberry, Prof. J. S.: on classification of ore-deposits [203]; on origin of ores, 316.
Newcastle coal, Jefferson county, Ala., 135.
New Chum consolidated stamp-mill, Bendigo, Victoria, cost of milling at, 567.
New Mexico, copper-deposits of, 316, 607.
New Process for the Production of Pig-Iron, Refined Iron, Ingot-Metal, and Weld-Metal (SATTMANN and HOMATSCH) [lxxxvii.], 3.
New Zealand: gold in Coal Measures of, 344; stamp-mills of, 562 *et seq.*
Nöggerath, J., on alterations produced by mineral waters, 241, 288, 599.
Nonesuch copper mine, Lake Superior district, Mich. [329].
North Chicago Rolling-mill Co., experiments in economy in fuel by, 372.
North Iron Hill, Leadville, Colo., ore-deposits of, 600.
North Ophir silver-mine, Comstock Lode, Nev., high temperature of water in, 224.
North Star stamp-mill, Grass Valley, Cal., cost of milling at, 567.
Norway, iron-ore deposits of [323], 325.
Nouel and Mesuré, optical pyrometer of, 435.

Offenbánya gold-mines, Dacian district, Transylvania, 275, 278, 285.
Officers of the Institute, past and present, vii., lxxiv.
OLCOTT, E. E., remarks in discussion of Mr. Rickard's paper on the gold stamp-mill, 549.
Old Telegraph silver-lead-mine, Salt Lake county, Utah [297, 300].
Ontario stamp-mill, Park City, Utah, 136.
Open-hearth metal, microstructure of, 52.
Ore-crushers, Dodge [547].
Ore-deposition: of Comstock Lode, Storey county, Nev., 593; in fresh water, 308; John Woodward's opinions, two hundred years ago, 591; lateral-secretion theory, 248 *et seq.*, 589, 597 *et seq.*; from sea-water, 306.
Ore-deposits: chemical views of French school, 203; "crustification," 207; in crystalline schists and eruptive rocks, 321; detrital, 337; examples of classes of, 262; formed by chemical and mechanical influences of surface region, 331; genesis of, 197; hysterogenites, 211; hysteromorphous, 331; heteromorphous, of older geological formations, 342; idiogenous and xenogenous, 205 *et seq.*; metamorphous, 304: metasomatic, in soluble rocks, 318; origin of, in deep regions, 247; precipitates from ascending springs, 263; at Przibram, Bohemia, 252 *et seq.*, 272; at Raibl, Carinthia, 252 *et seq*; of Rodna, Transylvania, 283; in soluble rocks, 253; by solution in rock-cavities, 207 *et seq.*; in spaces of discission, 264; systems of classification hitherto employed, 199; *verchoviky*, or surface, 335.
Ore-dressing in Gilpin county, Colo., in 1873, 547.

Ore-mixture for blast-furnaces: of Colorado Fuel and Iron Co., 581; of Pottstown Iron Co., 581.
Ore-veins: in the neighborhood of eruptive masses, 271; in stratified rocks, 269; wholly within large eruptive formations, 274.
Orient iron-ore, Colo., 577: analysis of, 580.
Origin of ore-deposits in the deep regions, 247.
Osmond, F.: on Beta-iron theory, 150; on microscopic metallography, 608 *et seq*; theory of hardening steel, 520, 538.
Otis Steel Co., Cleveland, Ohio [645].

Pawley, R., on manganese-steel dredge-pins, 168.
Pennsylvania University, Philadelphia, Pa., number of mining-students graduated from, 445.
Pestarena stamp-mill, Italy, 555, 569.
Phillips, J. A.: on appearance of gold at Bessèges, France [345]; classification of ore-deposits by, 203; experiments at Morro Velho stamp-mill by, 554.
Phœnix stamp-mill, Maricopa county, Ariz., 551.
Phœnix stamp-mill, Otago, New Zealand, cost of milling at, 567.
Phœnix stamp-mill, Wynaad, India, cost of milling at, 567.
Phosphorus, influence of, on steel, 113 *et seq.*
Photometric instrument of Le Chatelier, 431.
Physics of Steel (A discussion of the papers by Howe, Martens, Osmond, Pourcel, Sauveur and Webster, read at the Chicago meeting, August, 1893), 608.
Pig-iron: analyses of, 580 *et seq.*; daily averages of silicon and sulphur in, at South Chicago blast-furnaces, 376 *et seq.*; new process for production of, 3; refining of, by new process, 6; Swedish, 615, *et seq.*; temperature of gray in blast-furnace, 437; tests of gray, 386; tests of white, 391.
Placet, chromium electrolytically produced by, 153.
Platinum, placer-deposits of, 340.
Pompanoosuc copper-mine, Windsor county, Vermont [604].
Poorman silver-mine, Burke, Idaho, electrical power in use at, 401.
Porcelain-bulb air-thermometers, 413.
POŠEPNÝ, F.: *The Genesis of Ore-Deposits* [lxxxv] 197; discussion, 587.
POTTER, E. C.: *Review of American Blast-Furnace Practice* [lxxxvii] 370; discussion, 577.
Pottstown Iron Co., Montgomery county, Pa., 113 [466]; blast-furnace practice of, 581.
Pouillet's thermo-electric pyrometer, 411, 413.
Pourcel, Alexandre, on segregation in ingots of steel and iron, 608 *et seq.*
Power, advantage of electric, in mining, 400 *et seq.*
Prettau in Tyrol, copper- mines of, 327.
Prince of Wales silver-lead-mine, Salt Lake county, Utah [297].
Prinsep's optical pyrometer, 411.
Proceedings of the Chicago meeting, being part of the International Engineering Congress, August, 1893 (condensed), lxxxv.
Przibram, Bohemia, ore-deposits at, 252 *et seq.*; 272.
Przibram Mining Academy, study of geology at, 204.
Pseudomorphs, change of mineral contents in, 210.
Publications of the Institute, lxxviii.
Pumpelly, R.: classification of ore-deposits by, 202; on Lake Superior copper-deposits, 328.
Pumping, electric, 404.
Pumps, Blake and Lawrence centrifugal, worked by electricity, 404.
Pyrometers: Braun-Hartmann electrical resistance, 441; Callendar, 417; comparison of, with ordinary thermometer, 438; Crova's spectro-, 430; Le Chatelier,

418; measurement of furnace-temperatures by optical, 436, 437; Musschenbroek, 410; Nouel and Mesuré optical, 435; Pouillet, 411, 413; Prinsep, 411; recording, 420, 424; Siemens, 415; Wedgwood, 410; Wiborgh air-, 441.
Pyrometric alloys, 430.
Pyrometry: calorimetric methods, 429; optical methods, 430; recent advances in, 407.

Queensland, gold in Coal Measures of, 344.
Quenching (see also heat-treatment of) steel, 468.
Quicksilver, consumption of, in stamp-mills, 566.
Quicksilver-mines: *California:* Lake county; Sulphur Bank, 225, 227, 233; *Austria:* Idria, 457.

Raibl, Carinthia: calamine-deposits of, 318; silver-lead-mines at, 289.
Rail-steel, heat-treatment of, 500, 526.
RAYMOND, R. W.: remarks in discussion of Mr. Rickard's paper on the gold stamp-mill, 560, 574; on classification of ore-deposits, 202.
Recent Advances in Pyrometry (ROBERTS-AUSTIN) [lxxxvii], 407.
Recording pyrometer, 420, 424.
Record of temperature of blast-furnaces, 426.
Red Mountain district, Colo., character of ore-deposits, 296.
Reed and Benson silver-lead-mine, Salt Lake county, Utah [297].
Regenerative furnace for crucible-steel, measurement of temperature of, by optical pyrometer, 437.
Regnault, condemnation of thermo-couples by, 415.
Reichenstein silver-mine, Valle Sacca, Hungary, 287.
Rensselaer Polytechnic Institute, Troy, N. Y., 657.
Review of American Blast-Furnace Practice (POTTER) [lxxxvii], 370; discussion, 577.
Reyer, Dr. E, on tin placer-deposits [341].
Rézbánya, Hungary, geology of ore-deposits at, 286.
Richards, Prof. R. H.: on American mining-schools [455]; organization of mining laboratory by, 460.
RICKARD, R., remarks in discussion of Mr. T. A. Rickard's paper on the gold stamp-mill, 546.
RICKARD, T. A.: *The Limitations of the Gold Stamp-Mill* [lxxxvi], 137; discussion, 545; Mr. Rickard in discussion of his paper, 561; remarks in discussion of Prof. Posepný's paper on the genesis of ore-deposits, 589.
Rio Tinto, Spain, limonite-deposits at, 332.
ROBERTS-AUSTIN, W. C.: *Recent Advances in Pyrometry* [lxxxvii], 407; on Beta-iron theory, 150.
ROBINSON, T. W., remarks in discussion of Mr. Potter's paper on American blast-furnace practice, 577.
Rock-cavities, mineral deposits in, 207 *et seq.*
Rock-salt mine at Máros Ujvár, Transylvania, 215.
Rock Springs coal, Wyoming, quality of, 134 *et seq.*
Rodna, Transylvania, ore-deposits, 283.
Royal Mint, England, melting temperature of gold and silver at, 436.
Ruda gold-mine, Dacian district, Transylvania, 275.
Rules of the Institute, lxxxi.
Russia: gold-placer-deposits of Ural Mountains, 337, 339; ore-deposits of Kackar district, in the Ural, 339.

Salt-mines: *Transylvania:* Máros Ujvár, 215.
Salt in rain-water, 236.
Sandberger, Dr. F., lateral-secretion theory of ore-deposition of, 248 *et seq.*, 589, 597 *et seq.*

Sandstones: copper, of Bohemia, 312; at Fontainebleau, France, 305.
SATTMANN, ALEXANDER, and HOMATSCH, ANTON: *A New Process for the Production of Pig-Iron, Refined Iron, Ingot-Metal and Weld-Metal* [lxxxvii], 3.
SAUVEUR, ALBERT: remarks in discussion of physics of steel, 653; on micro-structure of steel, 608 *et seq.*
Savage silver-mine, Comstock Lode, Nev., 224.
Sawyer, A. R., on Witwatersrand gold-field, South Africa [345].
Saxon stamp-mill, Thames, New Zealand, cost of milling at, 567.
Scandinavia, ore-deposits of, 324.
Sclerometer, Turner's for testing hardness of steel, 196.
Screens, stamp-mill, 139, 550, 563.
Sea-water, traces of metals in, 306.
Segregation: experiments to determine cause of, in steel, 634 *et seq.*; illustration of, in purification of water by freezing, 610; in iron and steel, 612 *et seq.*
Shaw, W. N., on pyrometers, 416.
Shoes and dies for stamp-mills, 137, 549, 561; wear of, 562.
Siberia, Altai region, ore-deposits of [338, 341].
Siemens-Martin open-hearth furnace, measurements of temperature of, by optical pyrometer, 437.
Siemens, Sir William, on measurements of high temperatures, 414; pyrometer of, 415.
Silicon: daily averages of, in pig-iron at South Chicago blast-furnaces, 376; effect of, upon iron, 151.
Silicon-steel, analyses of, 196.
Silver, melting temperature of, at Royal Mint, London, England, 436.
Silver-lead-mines (see also silver-mines): UNITED STATES: *Nevada:* Eureka county; Eureka, 298, 300; *Utah:* Salt Lake county; Emma [297]; Flagstaff [297]; Old Telegraph [297, 300]; Prince of Wales [297]; Reed and Benson [297]. OTHER COUNTRIES: *Carinthia:* Raibl; Struggl, 291; *Greece:* Laurium, 319; *Transylvania:* Rodna; Benyes, 286.
Silver-mines (see also silver-lead-mines): UNITED STATES: *Colorado:* Lake county; A Y, 602; Minnie, 602; Ouray county; Virginus, 400; *Idaho:* Shoshone county; Burke, Poorman [401]; *Nevada:* Esmeralda county; Aurora [298]: Storey county; Belcher [280]; California, 280; Comstock Lode, Chollar Mining Co. [401]; Consolidated Virginia, 280; Gold Hill [224]; Hale and Norcross [224]; Justice, 280; North Ophir, 224; Savage, 224; Yellow Jacket [224, 280]; White Pine county; Eberhardt, 298; *Utah:* Juab county; Hidden Treasure [297], 298; Summit county; Daly [135]. OTHER COUNTRIES: *Germany:* Erzgebirge; Gottes Geschick, 222, 233; Freiburg; Bescheert Glück, 268; Churprinz, 222, 267; Joachimsthal; Einigkeit, 223, 233; Mitweida, Alte Hoffnung Erbstollen, 222; *Hungary:* Valle Sacca; Reichenstein, 287.
Silver-ores, deposits at Rézbánya, Hungary, 287.
Silver Reef mining district, Utah, 315.
Sjögren, A., on iron-ore deposits in Sweden, 323.
Slag, analysis of, 25.
Slickensides: at Raibl silver-lead-mines, 290; in Scandinavian mines, 324.
Smith, tests of cast-iron in Dr. Percy's laboratory by, 397.
Snelus on segregation of steel-ingots [633].
Sorby, Dr., microscopic study of iron by, 150 *et seq.*
South Africa, gold-deposits of, 344.
South Chicago blast-furnaces: daily averages of silicon and sulphur in pig-iron at, 376 *et seq.*; experiments in economy in fuel-consumption at, 372.
South Clunes United Stamp-mill, Clunes, Victoria, cost of milling at, 567.
South Dakota, gold-deposits of Black Hills, 343.
South Spring Hill Stamp-mill, Amador county, Cal., cost of milling at, 553.

Spaces of discission, 208, 264.
Spaces of dissolution, 208.
Spanish gold-mine, Amador county, Cal. [553].
Specific gravity of manganese- and carbon-steel, 195.
Specific heat of manganese-steel, 192.
Spilsbury, E. G., paper by Murgue translated by, 63.
Spring-water, analysis of, 611.
Stamp-mill practice: amalgamating-table, 143; in Australia, 143, 554 *et seq.*; in Black Hills, South Dakota, 553; in California, 138 *et seq.*, 550 *et seq.*; Colorado and California mills, 138 *et seq.*, 550 *et seq.*; consumption of quicksilver, 566; cost of milling gold- and silver-ores, 144, 553 *et seq.*; in Gilpin county, Colo., 137 *et seq.*; 545 *et seq.*; mortars, 140, 551, 565 *et seq.*; in New Zealand, 562 *et seq.*; revolutions of stamp, 141, 568; screens, 139, 550, 563 *et seq.*; shoes and dies, 137, 549, 561; temperature of water before and after leaving batteries, 571; in Venezuela, 553 *et seq.*; wear of screens, 564; wear of shoes and dies, 562; weight and efficiency of stamp, 138 *et seq.*
Stamp-mills (see also gold stamp-mills, lixiviation-works, etc.): UNITED STATES: *Alaska:* Douglass Island; Treadwell [553, 564, 567]; *Arizona:* Maricopa county; Phœnix, 551; *California:* Amador county; 551; Gover, 567, 568, 570; Keystone [553]; South Spring Hill [553]; Stewart [553]; Wildman [567]; Nevada county; North Star, 567, 568; *Colorado:* Gilpin county; Hidden Treasure, 545, 567, 568; *South Dakota:* Black Hills; Deadwood Terra [553]; Homestake [553]; *Utah:* Summit county; Park City, Marsac, 134, 585; Ontario, 136. OTHER COUNTRIES: *Australia:* Queensland; Excelsior, 567; Victoria; Britannia [567]; Garden Gully United, 568; Harrietville, 568; New Chum Consolidated, 567; South Clunes United, 567; *Brazil:* Morro Velho, 554; *Great Britain:* South Wales; Morgan, 567; *India:* Kolar; Mysore, 567; Wynaad; Phœnix, 567; *Italy:* Pestarena, 555, 569; *New Zealand:* Otago; Phœnix, 567; Thames; Mountain, 567; Saxon, 567; *South Africa:* Johannesburg; Jumpers, 567; May Consolidated, 567; *Venezuela:* Caratal; El Callao, 553, 567.
Stamps for gold stamp-mills, weight and efficiency of, 138 *et seq.*
Stanger, W. H., tests of forged manganese-steel by, 177, 178.
St. Avold, copper-ores in sandstone of, 312.
Steamboat Springs, Washoe county, Nev., 229 *et seq.*
Steel: analyses of, 158, 196, 612, 621; analysis determining absorption of sulphur, 624; carbon theory of hardening, 495 *et seq.*; care in hardening and tempering, 155; critical points of carbon, 476; effect of hardening and tempering, 149 *et seq.*; effect of heat on tensile properties of, 532; effect of water-quenching, 150 *et seq.*; electrical conductivity of, 194; experiments on phenomena of diffusion, 621 *et seq.*; experiments on toughening manganese, by sudden cooling, 467; hardening effect of sulphur, carbon and phosphorus, 113 *et seq.*; heat-treatment of, 466 *et seq.*, 614; heat-treatment of rail, 500, 526; influence of temperature on, 466 *et seq.*; iron alloys with special reference to manganese, 148 *et seq.*; manganese, 159; micro-structure of, 653; Osmond theory of hardening, 520. 538; physics of, 608; quenching, 468; relations between chemical constitution and physical character of, 113; relation of ductility and hardness, 497 *et seq.*; scale of hardness by Turner's sclerometer, 196; tables of ultimate strength under various conditions, 116 *et seq.*, 609; temperature at casting measured by optical pyrometer, 436, 437; tool-steel, 158; toughness and resistance to fracture of cast manganese, 161; ultimate strength increased by manganese, 114 *et seq.*
Steel-rails: composition of, 651; elastic limits, 648; micro-structure, 649; toughness 651.
Steel-works: *New Jersey:* Hudson county; West Bergen [466]; Hunterdon county; Taylor Iron and Steel Co. [476]: *England:* Sheffield; Hecla, 159 *et seq.* [612].
Stelzner, Dr. A. W., on deposits of tin-ore, 342.

Sterling Steel Co., Pittsburgh, Pa. [466].
STETEFELDT, C. A.: *The Consumption of Fuel in the Taylor Gas-Producer Plants at the Aspen and Marsac Mills Compared* [lxxxvii], 134; discussion, 585.
Stetefeldt roasting-furnace, 134, 585.
STEVENSON, A. A., remarks in discussion of physics of steel, 632.
Stewart stamp-mill, Amador county, Cal., cost of milling ore at, 553.
Strafford copper-mine, Orange county, Vermont [605].
Structural features of the deposits of mineral springs, 244.
Struggl silver-lead-mine, Raibl, Carinthia, 291.
Sturgeon, galvanometer of, 415.
Sturtevant blower worked by electric motor, 406.
Subterranean water-circulation, 212.
Sulphur: allotropic changes of, 154; in cast-iron, 382; daily averages of, in pig-iron at South Chicago blast-furnaces, 376; hardening effect of, 113 *et seq.*; in Sulphur Bank quicksilver mine, Cal., 225; tests for diffusion of, in steel, 622 *et seq.*
Sulphur Bank quicksilver mine, Lake county, Cal., thermal waters at, 225, 233, 234.
Sulphur in Cast-Iron (KEEP) [lxxxvii], 382.
Summer school of mining, 461.
Sunshine Coal, Garfield county, Colo., 135.
SWAIN, PROF. G. F., remarks in discussion of Prof. Christy's paper on American mining schools, 657.
Sweden: Åmmeberg, zinc-blende mine at, 326; copper- and gold-ores [325]; iron-ore deposits of Taberg, 322.
Switzerland, iron-ores of, 321 *et seq.*

Taberg, Sweden, iron-ore deposit of, 322.
Tables: of calculations of results in new process for producing pig-iron, 25 *et seq.*; of coal consumption per ton of ore at Marsac and Aspen mills, 134; of ultimate strength of steel, 116 *et seq.*
Tait, Prof., on thermal and electrical conductivity [193].
Tallawang gold-district, New South Wales [344].
Tasmania, gold in Coal Measures of, 344.
Taylor gas-producer plants at Aspen and Marsac mills compared, 134, 585.
Taylor Iron and Steel Co.'s works, High Bridge, N. J. [476]; tests of manganese-steel axles and car-wheels at, 173, 183.
Temperature: appliances for recording, 407 *et seq.*; influence of, on steel, 466 *et seq.*; of mineral waters, 233; record of hot-blast, in furnaces, 426; record of measurements by optical pyrometer, 434 *et seq.*; of water before and after use in stamp-mill batteries, 571.
Tempering, effect of, on steel, 155 *et seq.*
Tensile-tests of forged manganese-steel, 176.
Terre Noire Co., France, ferro-manganese produced by, 159.
Tests: of almost pure iron prepared from purest known Swedish bar, 148; of boiler-plate, 629 *et seq.*; of cast-iron, 384; of forged manganese-steel, 176; of ingot-iron in cast ingots, 42 *et seq.*; of manganese-steel, 160 *et seq.*; of manganese-steel car-wheels, 173; of manganese-steel tires, 185; of steel plates, 118 *et seq.*
Thermal conductivity of manganese-steel, 192.
Thermal waters encountered in mines, 223 *et seq.*
Thermo-couple, value of, in pyrometry, 412 *et seq.*
Thermometers; air, 408 *et seq.*; early forms of, 408; porcelain-bulb, air-, 413.
Thomas blast-furnaces, Hokendauqua, Pa. [379].
Thomas metal, micro-structure of, 49 *et seq.*
Thorncliff collieries, South Yorkshire, England, 176.
Thuringia, *kupferschiefer* of, 309.
Tilden, Prof., on changes in structure of bodies [154].

Tin: allotropic changes of, 154; placer-deposits of, 341.
Tin-deposits: of Cornwall, England, 323; formation of, 323.
Tin-mines: *England:* Cornwall, East Wheal Lovell, 324.
Tires of manganese-steel, 185.
Tool-steel: analyses of, 158; heating and cooling of, 476 *et seq.*
Toughness of manganese-steel, 161, 186.
Transylvania: gold stamp-mills at Verespatak, 145; mining rock-salt at Máras Ujvár, 215.
Treadwell stamp-mill, Douglass Island, Alaska, cost of milling at, 553, 564, 567.
Tube-muffle furnace, 535.
Turner, Prof.: tests of hardness of different steels made by, 196; tests of cast-iron by, 396.
Tyrol, copper-mines of Prettau, 327.

Underground waters: ascending, encountered in mines, 222; deep circulation of, 220; heat of ascending, 224; vadose circulation of, 213.
United States: mineral product of, for 1880 and 1891, 447; personnel of mineral industry of (from Eleventh Census), 450.
University of Michigan, Ann Arbor, Mich., number of mining-students graduated from, 445.
Ural mountains, gold-districts of [266].
Utah: character of ore-deposits, 297; Silver-Reef mining district, 315.

Vadose underground circulation, 213 *et seq.;* filling of open spaces formed by, 217.
Vallé lead-mines, Jefferson county, Mo., 261, 302.
Ventilation of mines by electric power, 406.
Verchoviky, or surface ore-deposits, 335.
Verespatak, Transylvania, gold-mines, 246 *et seq.*, 276; gold stamp-mills, 145.
Vermont, copper deposits of, 604.
Vermont copper-mine, Orange county, Vermont, 604.
Vesuvius lead-mine, Bavaria, Germany, 314.
VEZIN, HENRY A., remarks in discussion of Mr. Rickard's paper on the gold stamp-mill, 547.
Virginius silver-mine, Ouray county, Colo., use of electrical power at, 400.
Vulkoj gold-mine, Dacian district, Transylvania, 275, 276.

Waldenstein, classification of ore-deposits by, 200.
Warwick blast-furnace, Pottstown, Pa. [379].
Washington and Lee University, Lexington, Va., number of mining-students graduated from, 445.
Washington University, St. Louis, Mo., number of mining-students graduated from, 445.
Water-circulation, subterranean, 212.
Water-gauge for measuring loss of head of air-currents in mine gangways, 70.
Water-quenching, effect of, on steel, 150 *et seq.*
Waters, analyses of: mineral, from Steamboat Springs, Nev., 229, 234; encountered in mines, 234.
Waterson, J. J., on kinetic theory of gases, 413.
Water-toughening of manganese-steel, 467.
WEBSTER, WILLIAM R.: *Further Observations on the Relations Between the Chemical Constitution and Physical Character of Steel* [lxxxvii], 113; for discussion see "Physics of Steel," 608; remarks in discussion of physics of steel, 608.
Wedgwood pyrometer, 410.
Weld-metal, new process for production of, 3.
Wellman gas-producer, 587.

Werner, A., theory of ore-deposits of, 199.
West Bergen Steel Works, Hudson county, N. J. [466].
Westminster Testing Works, London, tests of forged manganese-steel at, 177, 178.
Weston, tests of cast-iron in Dr. Percy's laboratory by, 396.
Westphalia, copper-ores of, 310.
Whitney, Prof. J. D.: classification of mineral deposits by, 202 *et seq.*; on lead- and zinc-ores of Wisconsin [304].
Wiborgh air-pyrometer, 441.
Wildman stamp-mill, Amador, Cal., cost of milling at, 567.
WINCHELL, HORACE V., remarks in discussion of Prof. Posepný's paper on the genesis of ore-deposits, 591.
Wingham on non-magnetic character of Beta-iron, 189.
Winklehner, H., on rock-salt of Persian Gulf, 215.
WINSLOW, ARTHUR, remarks in discussion of Prof. Posepný's paper on the genesis of ore-deposits, 588.
Wisconsin, lead- and zinc-regions of, 301, 303, 588.
Wisconsin University, Madison, Wis., number of mining-students graduated from, 445.
Witwatersrand gold-field, Transvaal, South Africa, 344.
Woodward, John, "Essay towards a Natural History of the Earth," by, 591.
Woolwich Arsenal, England, temperature of gases and metal at, 436.
Wright, Dr. Alder, on peculiarities of aluminum and antimony [155].
Wrought-iron, oldest pieces of, in existence, 156.
Wyoming, quality of Rock Springs coal of, 134 *et seq.*

Xenogenous mineral deposits, 207.

Yellow Jacket silver-mine, Storey county, Nev. [224, 280].
Yellowstone National Park: analyses of waters, 234; chimney-like conduits built by geysers, 231.

Zinc-mines: *Sweden:* Åmemberg (zinc-blende), 326.
Zoppe, G., on salt in rain-water, 236.

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